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GRANT NO: DAMD17-94-J-4318

TITLE: Evaluation of a Digital Telemammography System: A Model for a Regional System

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REPORT DATE: October 1995

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

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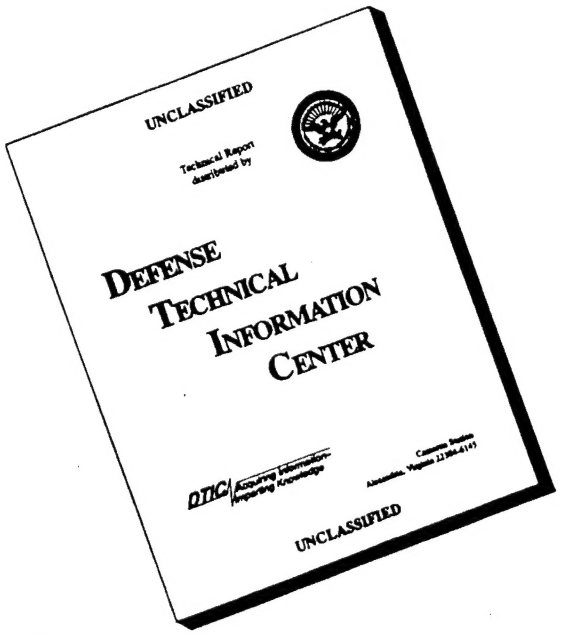


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# REPORT DOCUMENTATION PAGE

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| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | October 1995 | Annual 16 Sep 94 - 15 Sep 95 |

**4. TITLE AND SUBTITLE**
Evaluation of a Digital Telemammography System: A Model for a Regional System

**5. FUNDING NUMBERS**
DAMD17-94-J-4318

**6. AUTHOR(S)**
Ellen Shaw de Paredes

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
University of Virginia
Charlottesville, Virginia 22906

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution unlimited

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

The research hypothesis being tested is that a telemammography system utilizing a laser film digitizer at the transmitting site (with a 50-micron pixel size for spatial resolution and a 12-bit pixel range for contrast) and interactive two grayscale display monitors (2048 x 2560 x 8/12 bits) at the receiving site can be used to interpret mammography images with an accuracy level sufficient for primary diagnosis. To test the research hypothesis, the following four aims are to be completed: (1) Collection of 200 normal cases and 200 abnormal cases of specifically selected analog mammographic film images and patient data for use in evaluating a telemammography system; (2) convert the collected database of analog mammographic films into digital arrays using a laser film digitizer with a 50-micron pixel spot size and 12 bits per pixel of dynamic range; (3) conduct an ROC analysis of the retrospective database of the analog mammographic image and digitized arrays displayed on the two monitor interactive gray scale workstation, each monitor displaying 2048 x 2560 x 8/12 bit portions of the 4K x 4K digitals arrays; (4) implement a digital transmission for evaluation of the telemammography system; (5) implement and test a quality control program; and (6) evaluate the throughput rate of the implemented telemammography system.



| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
|---|---|
| FBDI (Full Breast Digital Image), DS-0, T1, DS-1<br>breast cancer | 141 |
| | 16. PRICE CODE |

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | Unlimited |

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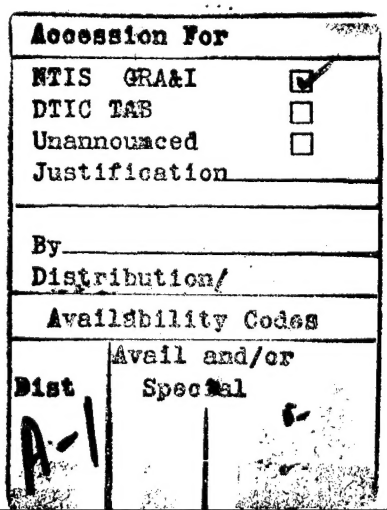


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Table of Contents

INTRODUCTION

1.1 Nature of the Problem

Routine mammograms are an essential element of health care for adult women (1-5). Digital technology promises improved lesion detection and, in conjunction with teleradiology, improved access to mammography compared to current conventional techniques (6,7). However, because mammography requires high spatial resolution over a large area, good contrast resolution over a large dynamic range, and high detective efficiency for x-rays, the development of full-breast digital imaging (FBDI) technology has been slow (reviewed in 8). While FBDI technology will be implemented over the next three to five years, the current screen film mammography examinations will remain the standard for use in teleradiology systems. Digital imaging methods will ultimately replace analog (screen-film) systems; filmless systems will become an integral part of local-area and wide-area networks and digital x-ray mammography units will eventually reach the market. These modalities generate large volumes of digital data and thus will require an efficient communications interface if the data are to be managed in reasonable time frames. Furthermore, a standard interface must be implemented lest the telemammography benefits envisioned for the near future disappear into a costly and inefficient world of incompatible systems. We believe it is essential now, during the prototype stage of system development, to implement and evaluate an interface that satisfies the Digital Imaging and Communications in Medicine (DICOM 3.0) standard (9-13).

To make transmission and archival of digital image files practically feasible, image compression algorithms (14-16) are necessary as a means of compacting and reducing the enormous data sets generated by a digital full-breast mammogram (4K x 4K x 2 Bytes = 32 MB/image x 4 images/screening exam, or 8 images for comparing past and present exams). Using software (AWARE), Inc, Waltham, MA) for wavelet compression (17-23), we have studied wavelet transforms of digitized screen-film mammograms at compression ratios of 50:1 to 100:1; and have determined from a contrast-detail phantom study that 50:1 is an acceptable ratio. Wavelet transforms are multiresolution decomposition tools, with the kernel of wavelet transform obtained by dilation and translation of a selected bandpass filter. Compression for digitally acquired images will demand new filter designs to attenuate the effects from the high detective quantum efficiency and low noise of digital detectors without distorting mammographic features.

The use of T1 digital transmission service (1.544 Mbits/sec signaling speed) is expensive for use in telemammography. An estimate of T1 costs is $19/month/mile per site and access charges of approximately $1,000 per month. The use of a successful compression ratio of 24 to 1 enables a DS-O digital service (64K bits/sec) to accomplish the same signaling rate of a DS-1 (equivalent to T1 service) channel.

Digital display technologies are limited, for the near future, to 8/12 bit pixel laser film printers and 2K x 2.5K interactive

high-resolution gray-scale monitors. We have extensive experience with both of these display modalities. Like other components of the digital mammography system, the display modalities face special challenges as a result of the amount of data generated by digitally acquired examinations. The critical effort with the laser film printer is the development of appropriate look-up tables (24-27), so that the digital detector output, which is a 4K x 4K digital array with 63-micron pixel size and 12 bits/pixel of dynamic range, is optimally transferred at 8/bits per pixel to the laser-imaged films. In the case of the gray-scale displays, the problems are more complex (28-34). To be usefully implemented, there are four standard mammographic (screening) views that must be displayed (craniocaudal (CC) and mediolateral oblique (MLO) views of each breast) at a two-monitor workstation; in some cases, at least two diagnostic views (spot compression or magnification) ( performed in two different projections (usually 90° apart) will also be viewed, as will both the current and the previous examination. A mammographer using a gray-scale monitor will need rapid displays with easily used interactive commands. In addition, the system must effectively display the 4K x 4K image matrix on a 2K x 2.5K screen. A well-designed display protocol meeting all these needs could become a standard implemented by a digital signal processing (DSP) board or an accelerator board. Such a standard would enable faster throughputs for the mammographer and aid in the establishment of quality control standards for visualizing digital mammography examinations.

## 1.2 Purpose of the Present Work

The research hypothesis being tested is that a telemammography system can interpret mammography images with an accuracy level sufficient for primary diagnosis utilizing a film digitizer at the transmitting site (with a 50-micron pixel size for spatial resolution and 12 bit pixel range for contrast) and interactive grayscale display monitors (2048 x 2560 x 8/12 bits) at the receiving site.

A successful telemammography system will provide benefits in the following four areas:

A. PRIMARY DIAGNOSIS. Telemammography offers the ability to provide mammographic consultations to underserved and remote areas. Achieving the image quality required of a telemammography system for primary diagnosis will enable an outreach program to enhance a region's breast screening programs and to improve patient care.

B. INTEGRATION OF MAMMOGRAPHY GROUP PRACTICE DISTRIBUTED OVER MULTIPLE IMAGING CENTERS. As the awareness regarding the role of mammography in early detection of breast cancer increases, so does the need for accessibility to low cost screening mammography. More and more practices are responding to the rapidly growing utilization of mammography by opening satellites to imaging practices. Telemammography would enable a group with a limited number of expert mammographers to handle multiple off-site practices. Additionally, if

appropriate for the practice, the radiologist could supervise screening mammograms off-site and determine the need for any additional views at the time of the examination instead of having the patient return at a later time. Image quality could also be supervised off-site via telemammography. Another advantage of this system is that, due to efficiencies of scale, mammography costs would be lower and a lower fee for interpretation could be maintained without the need for an on-site radiologist. In part, this would be related to alleviating the need for the physician to travel to and from various satellite screening sites.

C. OVERREADING OF MAMMOGRAPHY IMAGES. There is increasing emphasis on the interpretive skills of radiologist's reading mammograms as part of the quality assurance process monitored both by the ACR Mammography Accreditation program and by the Food & Drug Administration. Residency programs are offering more time in mammography rotations now compared with only a few years ago; there have been formal standardized training programs for radiology residents and mammographic technologists through the ACR-CDC Cooperative Agreement. Nonetheless, the impact of the accreditation guidelines and the training programs will not be immediate, and there remains a need for expert mammographic interpretation in many practices. With

telemammography, a small number of expert mammographers could provide consultation services or second readings of mammograms for a larger number of general radiologists, and improve the quality of care. Additionally, the data and images for patients in a region could be stored and utilized for the development of a regional mammography database.

D. IMPROVED CONSULTATION WITH SURGEON AND PCP. Primary care physicians and surgeons could review the mammograms on their patients without the need for "signing out" the original films, thus providing more reliable continuing service and decreasing the risk of loss of films. On a broader scale, the utilization of telemammography at multiple radiology practices in a referral region could provide greatly improved access to a patient's prior examination, regardless of where the patient obtained subsequent mammograms. The importance of such transmission would be multifocal: original films would not need to be mailed, risking their loss, the cost of making copy films could be avoided: and the facility interpreting the current study would have a much more rapid access to the prior exams, thereby, improving the accuracy of diagnosis and diminishing the anxiety of the patient who is waiting for her final results.

## 1.3 Methods of Approach

Three tasks are required in support of evaluating the research hypothesis.

Task 1. A selected set of analog mammographic films will be collected and digitized using a laser film digitizer set at a 50-micron spot size and a 12-bits dynamic range. An ROC analysis will be conducted on the analog mammographic films and the digitized films displayed on grayscale monitors (2048 x 2560 x 8/12 bits).

Task 2. A digital communication network will be implemented between the Department of Radiology Breast Imaging Center in the Diagnostic Center for Women (primary Care Center Building, UVa) and the off-campus outpatient Virginia Mammography Center (Northridge facility, UVa, 8 miles from the campus). A laser film digitizer (50-micron spot size, Model 150, Lumisys Inc, Sunnyvale, CA) and computer workstation (SUN, SPARC Model 40) will be installed at the Northridge. Transmission of the digitized mammographic films will be over a T-1 carrier (1.544 Mbits/sec signaling speed) to the department's PACS and displayed on 2048 x 2560 x 8/12-bit grayscale monitors. A protocol for end-to-end telemammographic quality control will be implemented.

Task 3 A performance evaluation will be conducted of the teleradiology system using the metrics of response time, throughput, reliability, and clinical acceptance.

We divided the above three tasks into the following aims:

Aim 1. Collection of an adequate retrospective database of

analog mammographic film images and patient data for use in evaluating a telemammography system.

Aim 2. Convert the collected database of analog mammographic films into digital arrays using a laser film digitizer with a 50 micron pixel spot size and 12 bits per pixel of dynamic range.

Aim 3. Conduct an ROC analysis of the retrospective database of the analog mammographic images and the digitized arrays displayed on the 2048 x 2560 x 8/12-bit grayscale monitors.

Aim 4. Implement a digital transmission service between the Virginia Mammography Center at Northridge and the PACS in the University of Virginia Department of Radiology and its workstations including that in Diagnostic Center for Women.

Aim 5. Design, implement, and evaluate an end-to-end quality control program for the telemammography system.

Aim 6. A performance evaluation will be conducted of the telemammography system using the metrics of response time, throughput, reliability, and clinical acceptance.

## 2. Experimental Methods and Results

### 2.1 Statement of Work.

The proposed statement of work for the contract was identified by the year and aim as follows. We present these Tasks and Aims, commenting on our current progress at the completion of the first year of the contract (in script font).

YEAR 1

TASK 1: Aim 1

* Complete collection of 200 normal and 200 biopsy-proven malignant analog mammographic films to form an image database (6 months to complete).
* Collect pathology and consultation reports for the 400 images in the database.
* Conduct an image quality control protocol on the image database to insure correct ground truth identification, correct diagnosis, and an adequate optical density range in each image.
* Conduct a review of the identified Regions of Interest (ROIs) to insure proper identificati on.

*We have completed the collection of 200 normal and 200 abnormal analog mammographic films to form our image data base (see Appendix I for a listing (coded by case number). (Abnormal cases include benign and malignant lesions, with pathology serving as gound truth.) We have completed the collection of patient data and will be adding the patient's age as well as demographic data. We conducted an image quality control protocol on the analog image database to insure correct ground truth identification, correct diagnosis, and the proper optical density range in each image. All cases were reviewed and lesions were analyzed and classified using ACR lexicon. The abnormal cases were also verified for presence of only one lesion. The abnormals selected reflected a range of*

*difficulty in lesion perception and analysis.*

*Normals were selected as normal based on the following: (1) Initial consultation reading was normal; (2) review of images showed no significant abnormality; and (3) follow-up mammogram at least 24 months later showed no interval change. Mammographic findings of intramammory lymph nodes, calcification of fat necrosis, dermal calcifications and vascular calcification are considered pathognomically benign and could be present on "normal" cases.*

*Parenchymal density for each case was classified on a scale of 1 to 4. (1 = fatty; 2 = scattered fibroglandular tissue; 3 = heterogenously dense; and 4 = extremely dense). The density of normal cases was matched to abnormals. There were an approximately equal number of fatty normals, fatty abnormals, etc.*

*The image database was initially collected together with an overlay sheet of clear plastic identifying the Regions of Interest (ROIs) to insure proper identification. Our intent was to digitize this RBI and use it for display on the grayscale workstations. We have discontinued this portion of the project as it introduces a bias in the reader response. That is, if only a 1K x 1K ROI is displayed to each reader, a bias is introduced by not displaying the full image.*

YEAR 1.

TASK 1: Aim 2

* Begin digitization of analog mammographic films (requires eight months to complete,

starting in last six months of Year 1 and two months of Year 2).

* Digitize the 400 analog mammographic images with a 50 micron pixel spot size and 12 bits per pixel of dynamic range.
* Conduct a review of the digitized images using the grayscale display workstations (2048 x 2560 x 8/12 bits) in the PACS network.
* Archive the 400 digitized mammographic arrays and the patient data in a relational database (Sybase) on the PACS network.
* Digitize the 400 mammographic images with a 23-micron spot size film digitizer (DBA, Fairfax, Virginia) and evaluate any significant difference between the 50-micron and 23-micron spot size digital arrays by the following: (a) registering and subtracting the RBI region, multiplying the difference image by 10, and calculating the mean square error; (b) displaying on the grayscale display stations the two digital arrays (50 micron and 23 micron) and inspecting the displayed images to detect any significant differences (each display station has two monitors).

*We have completed digitizing 350 of the 400 mammography cases. These have been digitized using a 50 micron spot size and archived*

*onto 8 millimeter DAC tape. These digital array images have been interactively cropped using a rectangular window in order to minimize the background of the digital image.*

*We have encountered two problems in accomplishing Task 1, Aim 2 of the first year. First, the software operating on our 16 two-monitor grayscale workstation was modified by EMED (E-Systems, EMED, San Antonio, TX) when changing our PACS from DOS to a UNIX operating system. Laser Film Digitized Images lacked the expected DICOM header block. It took two of our graduate students four months to discover this problem. Through the efforts of our graduate students, we are now able to load laser film digitization mammography films (4K x 4K) into our PACS and display them on the 2K x 2.5K grayscale workstations.*

*Second, our arrangement with DBA (Fairfax, Virginia) to digitize the 400 mammographic images at a 23-micron spot size (CCD detector) is not currently possible for the following reasons: (1) DBA expects for us to pay $5,000 a month (plus a maintenance charge of $800/month) to install their CCD film digitizer (we can not afford to do this); (2) the DBA CCD film digitizer that we had discussed is limited to 8 bits of dynamic range; (3) the use of 50 micron spot size on the laser film digitizer matches the sampling frequency required for analog film-screen mammography images when scatter is considered (scatter limits the radiographic information to a spatial resolution of approximately 7 lines per millimeter); and (4) the radiographic magnification of approximately 2.3 to 2.4 enables a spot size of 50 microns to be equivalent, in the actual*

*image size, to approximately 45 microns. We are currently conducting a study using 23 m spot size with a set of mammography cases (10 normal and 10 abnormal) to determine a measure of the image quality, using mean-square-values, to determine differences between 50 micron and 23 micron spot sizes.*

TASK 1: Aim 3

* Begin initial ROC curve analysis of mammographic analog films (8 months to complete, final 6 months of Year 1 and two months of Year 2) by six readers.

*We have completed the initial ROC analysis of the readers. We have expanded the number of readers from six to eleven. Image grading is conducted with the following gradings.*

*Masses 1 (definitely not present); 2 (probably not present); 3 (equivocal); 4 (Probably present); 5 (definitely present).*

*Microcalcifications 1 (definitely not present); 2 (probably not present); 3 (equivocal); 4 (probably present); 5 (definitely present).*

*Dilated lactiferous ducts 1; 2; 3; 4; 5.*

*Focal areas of asymmetry or architectural distortion 1; 2; 3; 4; 5.*

*Diagnosis of image 1 (definitely benign); 2 (probably benign); 3 (equivocal); 4 (probably malignant); 5*

*(definitely malignant).*

*Our initial ROC results are detailed in Appendix*

For year 2 the following Tasks and Aims are to be accomplished.

YEAR 2

TASK 1: Aim 2

* Complete digitization of the collection of the analog mammographic films (two months of Year 2, began in Year 1).

TASK 1: Aim 3

* Complete ROC analysis of mammographic analog films (requires two months of Year 2 to complete task began in the first year).

TASK 1: Aim 3

* Utilize the collected digitized image data set to perform an ROC curve analysis (requires six months) utilizing the 2048 x 2560 x 8/12 bit grayscale display stations in the University of Virginia PACS by six readers.

TASK 2: Aim 4

* Implement the T-1 connection between Northridge facility and the University of Virginia PACS (three months of Year 2).
* Test network for end-to-end fidelity.

TASK 2: Aim 5

* Design, establish, and test an end-to-end quality control program for validating a telemammography system.
* Operate the telemammography system to collect data for evaluating the quality control program.

For Years 3 and 4 the following Tasks and Aims are to be accomplished.

YEAR 3

TASK 1: Aim 3

* Complete the ROC analysis of digitized mammographic images displayed on 2048 x 2560 x 8/12 bit grayscale display stations in the University of Virginia PACS.

TASK 2: Aim 5

* Implement the end-to-end quality control program for evaluation and analysis.

TASK 3: Aim 6

* Implement a software data logger program which will record events on the telemammography system.
* Implement the performance evaluation using the metrics of response time, throughput, reliability, and clinical acceptance.

YEAR 4

TASK 2: Aim 5

* Evaluate the end-to-end image quality control protocol for the teleradiology system.

TASK 3: Aim 6

* Evaluate the performance evaluation of the teleradiology system.
* Continue with utilization of the teleradiology system to increase the statistical power of the analysis.

## 2.2 Database of Analog Screen Film Mammograms

Appendix IA lists by case number the image database cases together with their ground truth.

## 2.3 Reader Responses

Appendix IIA shows an example of data collection for reader responses for an individual case in the data file. Appendix IIB illustrates an example of the reader responses for all cases read to date by readers 2 and 6.

2.4 Format for additional clinical and image information to be input into data base (Appendix III)

Additional information as each case to be added to the database including the following: age, family history, history of previous breast surgery. Additional lesion characteristics are the following: size, level of suspicion, characteristics of mass (shape, margins, anad density), characteristics of calcification (morphology, number). This information is being verified and will be added to the database in the first quarter of the second year.

Complete demographic, clinical information will be entered into the database during year 2 using Mammographic Clinical History Sheet (Appendix IIIA). Mammograms have been classified based on abnormalities identified using ACR lexicon. The database will be expanded and completed by adding the mammographic findings using the ACR MagView Program (Appendix IIIB).

2.5 ROC Analysis

Appendix IV details the ROC results of the readers.

## 2.6 Interactive Grayscale Workstation Display Protocols

Acceptable display protocols are critical in using interactive gray-scale monitors. The acceptability of a protocol for displaying mammographic images may be judged in terms of the rapidity with which a user can accomplish tasks. Image processing and management steps impact the throughput rate of a display protocol, as do the demands of mammographers for specific organizations of images on the screen. One possible display protocol for a two-monitor workstation might be defined as follows. Monitor 1 displays a current exam (craniocaudal (CC), left and right breasts; mediolateral oblique (MLO), left and right breasts). Monitor 2 meanwhile displays either previous exams if available (CC- L&R; MLO - L&R) or previous and current left CC; previous and current left MLO; etc. Data from the radiology and the hospital information systems are displayed. Pre-set window and level functions could aid throughput, as could prefetching (acquiring the patients images from the archive file and storing on the workstation prior to the images being interpreted). At UVA, previous examinations archived on the long-term archive file could take up to 8 minutes to retrieve to the disk file at a specific workstation.

Images will be loaded onto digital tape in a display format consistent with the way in which they will be

reviewed in the clinical setting. Mammograms are typically viewed as mirror images, and if a lesion is identified in one breast the two views of that breast are reviewed.

Examinations will be stored on the digital tape in the following sequences:

1. Left mediolateral Oblique (MLO)

   Right MLO

2. Left craniocaudal (CC)

   Right CC

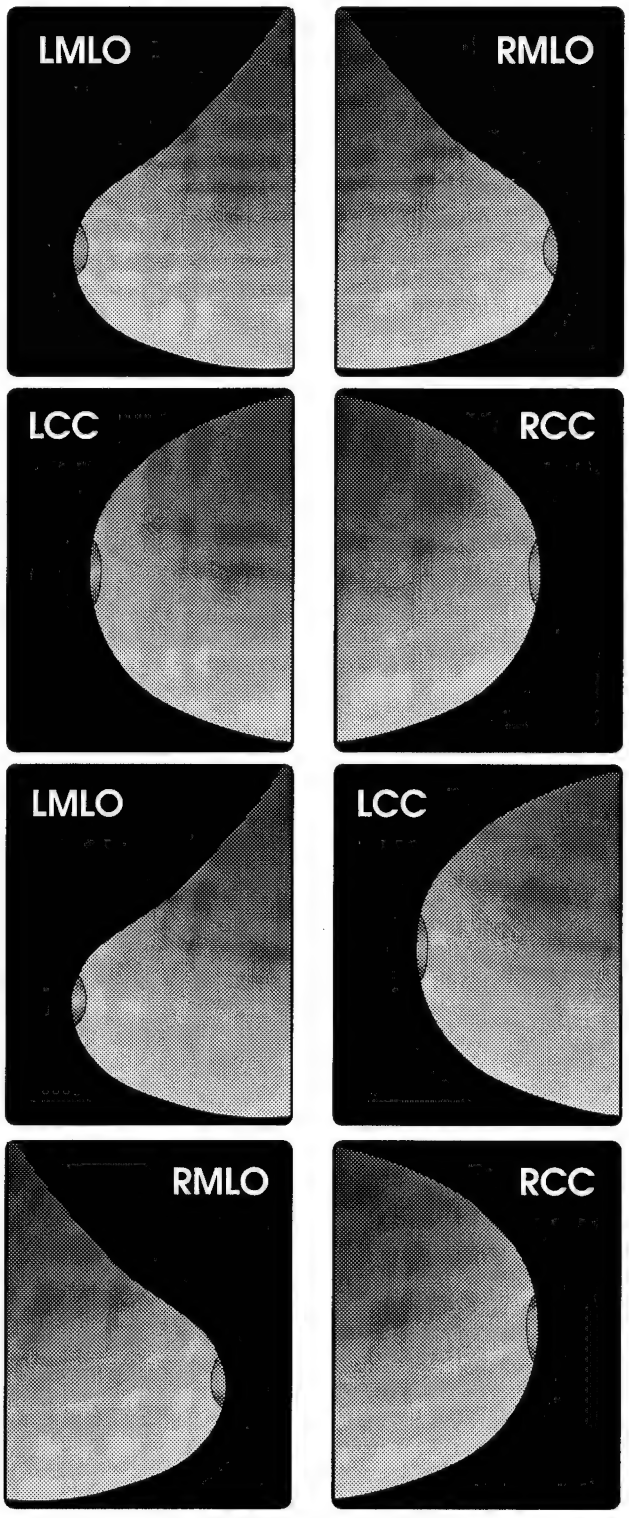
3. Left MLO and Left CC

4. Right MLO and Right CC

Two significant efforts are required to implement acceptable display protocols for a digital mammography gray-scale workstation; (a) development and evaluation of the protocols; and (b) hardware implementation.

First, we will design several plausible display protocols. Second, we will evaluate the protocols by transferring 40 digitized screen-film mammography cases from the PACS to an optical disk. These cases will be equally divided among masses, microcalcifications, architectural distortions,a nd focal asymmetries. The optical disks will have the images preloaded for each of the display protocols to avoid biasing the protocol evaluation with the frustration of the mammographer in loading a prescribed sequence. Third, four UVA and MCV

DISPLAY PROTOCOLS




Display A

Display B

Display C

Display D

mammographers will evaluate the lesions using each of the display protocols. A reader rating scale will be used for each case (Example, mass: 1 = definitely acceptable; 2 = probably acceptable; 3 = equivocal; 4 - probably unacceptable; and 4 = definitely unacceptable). The order of each question will be randomized as well as the cases. The reader data will be analyzed for the mean score. The times of initiation and completion of each study will be recorded for calculating the throughput times. A preferred display protocol will be identified on the basis of the mean score and a t-test.

The hardware effort is to implement the best display protocols, as evaluated by the mammography readers, onto a hardware platform. For the two-monitor system, using the UVA system as a testbed, we will incorporate the selected display protocol onto a DSP board or a Hewlett-Packard (HP) accelerator board using toolkits provided by HP. The hardware implementation on the UVA PACS two-monitor systems is not yet approved. HP is just now announcing their new accelerator board; we expect to have it available on-site by February 1996.

We are currently evaluating a set of display protocols.

## 2.6 Throughput Performance.

Cost-benefit analyses for digital telemammography

lie in the distant future, as they will need to reflect currently nonexistent relationships among costs, availability, efficacy, and quality-of-life features. An opportunity to analyze initial costs, however, lies in the present, created by the availability of the digital mammography environment described in this application. We have devised a cost analysis method in which, for any well-defined system, time can be used to create a relationship between the jobs accomplished per unit of time (the throughput rate) and resources used (costs) to accomplish those jobs. This novel strategy should be applicable to any mammography setting, or for that matter, to any clinical setting.

Table 1 illustrates the starting point for the analysis--a resource allocation table; the "job" in this case is a conventional mammographic examination, defined as beginning with patient registration and ending with the filed report (see table legend). The steps are listed in column 1. The estimated time needed to complete each step ($T_i$) is given in columns 2 of Table II; $T_i$ is assumed to be normally distributed, therefore 10 observations of each step provide enough sample points for estimating the mean time values. The resources used to accomplish the steps are shown as column headings (refer to table legend), and each resource's points of contribution are indicated in the table by "1." Thus

## Table I

**Resource Allocation for reading Film Mammography**
**MCV Mammography Department**

| Step | Clerk | Tech | Modality | Film Processor | Film Room Personnel | Resident | Radi-ologist | Avg. Time |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | T1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | T2 |
| 3 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | T3 |
| 4 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | T4 |
| 5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | T5 |
| 6 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | T6 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | T7 |
| 8 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | T8 |
| 9 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | T9 |
| 10* | | | | | | | | T10 |
| 11 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | T11 |
| 12 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | T12 |
| 13 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | T13 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | T14 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | T15 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | T16 |
| 17 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | T17 |

**Steps used:** 1 = Registration; 2 = Prior Film Retrieval; 3 = Image Acquistion; 4 = Film Processed; 5 = Quality Assurance; 6 = Re-acquisition and Processing; 7 = Films Hung; 8 = Review of Clinical Info.; 9 = Films Read; 10 = Additional views or Studies*; 11 = Write Early Reading; 12 = Report Dication; 13 = Notify Clinician; 14 = Review Results with Patients; 15 = Comparison with Prior Films; 16 = Dictate Addendum to Report; 17 = Filing of Report.

*Additional Views for Diagnostic Mammogram
1 = Resources Used
2 = Resources Not Used

## Table II

**Raw data for Reading Film Mammography Bottleneck Analysis**
**MCV Mammography Department**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T1** | 12 | 13 | 11 | 10 | 10 | 10 | 10 | 13 | 15 | 11 |
| **T2*** | 1.75 | | | | | | | | | |
| **T3** | 10 | 13 | 12 | 14 | 11 | 13 | 12 | 15 | 6 | 26 |
| **T4** | 4 | 5 | 3 | 6 | 5 | 5 | 5 | 5 | 5 | 4 |
| **T5** | 3 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 2 |
| **T6** | | | | 7 | | | | 8 | 7 | |
| **T7** | 0.33 | 0.66 | 0.17 | 0.83 | 0.25 | 0.83 | 0.17 | 0.25 | 0.25 | 0.17 |
| **T8** | 0.33 | 0.17 | 0.25 | 0.083 | 0.33 | 0.25 | 0.33 | 0.17 | 0.50 | .083 |
| **T9** | 0.25 | 0.58 | 0.75 | 0.25 | 0.42 | 0.75 | 0.33 | 1.00 | 1.50 | 0.41 |
| **T10*** | | | | | | | | | | |
| **T11** | 0.50 | 0.83 | 0.33 | 0.17 | 0.083 | 0.083 | 0.25 | 0.75 | 0.25 | 0.17 |
| **T12** | 1.42 | 0.75 | 0.83 | 1.08 | 0.50 | 1.83 | 0.83 | 2.33 | 1.75 | 0.83 |
| **T13** | 2.08 | 1.5 | | | | | | | | |
| **T14**** | 0.42 | 0.50 | 1.83 | 5.33 | 0.67 | 0.75 | 1.5 | 1.25 | 0.42 | 0.75 |
| **T15** | 0.58 | 0.58 | 0.75 | 0.92 | 1.5 | 2.25 | | | | |
| **T16** | 2.25 | 0.58 | 0.66 | | | | | | | |
| **T17#** | 0.46 | | | | | | | | | |

*T2 Calculation: 24 cases retrieved in 42 minutes, 42min/24cases = 1.75 min. per case
** Additional Studies: Ultrasound Study; uses tech, radiologist, and modality as resources.
Radiologist time: 1) 30 min. 2) 8 min.
Technologist time: 1) 39 min. 2) 16 min.
***T14 = time required to sign form letters for patients, Direct consultation has not been defined or measured.
Note: Review with Residents: two time trials - 1.83 and 2.00 minutes.

described, a mammographic exam becomes, for our purposes, a system comprised of identifiable resources and steps, and consequently suited to established methods for systems analysis.

One way to characterize the operation of a system is by its throughput rate (measured in jobs per second). Methods we have used previously to analyze PACS operations--bottleneck analysis and Jackson network analysis (35,36)--when applied to mammography will generate the throughput rate for each resource involved in the "job" of interest, and ultimately for the job as a whole. Cost can then be related to the system's throughput rate.

All systems have an operating region which is bounded by upper and lower limits on throughput. To define the upper bound on the throughput, a bottleneck analysis is performed, in which Little's law (37) is used to identify the rate-limiting resource for the case when the whole system is available for one job (eg, for one examination in our model). Little's law states that the mean number of jobs (e) within the system equals the mean throughput rate ($\lambda$) multiplied by the mean time in the system (t). Thus, $E = \lambda T$. The mean throughput rate for each resource will increase until one resource is completely utilized (100%); this point of 100% utilization is termed a "bottleneck," ie, the upper bound

beyond which the system's throughput rate cannot increase. To calculate throughputs, one assumes that each resource in turn is the bottleneck. If the film processor in Table 1 is the bottleneck, for example, its throughput is given as $\lambda_{\text{film processor}} = 1/(T_4 + T_6)$. If there are two processors then $\lambda_{\text{film processor}} = 2/(T_4 + T_6)$. The resource with the smallest throughput rate is the true bottleneck. In our example, the bottleneck of the upper bound is the technologist at 0.0371 jobs/second).

The lower bound of the throughput describes the system when more than one demand is placed on it (in our example, the demand for one than one examination). The lower bound throughput is the number of simultaneous demands possible before the next demand is forced to wait for service. Lower-bound values shift depending on the resource being evaluated. for example, we may want to examine the bound placed on our model mammography unit's throughput by the number of clerks (C); in which case, we define $T_{clerk}$ as the time used for the clerk's task(s) and $T_{system}$ as the sum of time used by all other system resources ($T_{tech} + T_{modality} + ...$etc). We then calculate the lower bound on the mean throughput as $\lambda \geq C/[T_{clerk} + C(T_{system})]$.

Figure  demonstrates mean throughput rates ($\lambda$) as a function of the number of examinations in our model system, lower-bounded in this case by the number of

clerks. The area between the upper bound (determined by bottleneck values for the resources) and the lower bound (all resources are busy as of the current demand) is the operating region for the system. Once this region has been defined, it becomes possible to validate its predicted upper and lower bounds in a real system, which will follow the predictions if the model has accurately described the steps and resources necessary to the job. If the real setting behaves differently, the model can be corrected by incorporating the differences in steps or resources.

The costs for each resource can be determined from financial records. The UVA Hospital has recently implemented an accounting system capable of generating detailed cost analyses; for purposes of this study, actual costs will be supplemented with imputed costs for noncommercial equipment. One purpose of the throughput/cost analysis is to establish what economists describe as a "production function." This is a mathematical relationship between the mix of input resources, the total volume of production, and the cost/unit of output. In a typical industrial production situation, one observes that cost/unit is relatively high when volume is very low, but declines as volume increases. At some point there are "diseconomies of scale" (Something like "bottlenecks") and cost/unit

begins to increase. We would expect in our analyses to observe a cost function where the cost per job first decreases as throughput expands and then at some point increases.

## 3. Conclusions

### 3.1 Implications of Completed Work.

At the end of the first year of activity, we find researches across the country asking if they could obtain the 400 cases of digitized screen film mammography and the patient data. We plan to complete this database by March 1996. This database will be sent to requesting researchers with prior approval of the U.S. Army for the cost of the 8 mm DAC Tape. All patient data has been appendixed to the digitized screen-film mammography using the DICOM 3.0 Data format standard. We envision that this database will be used by other researchers for the following possible projects.

a. Developing and evaluating computer aid diagnosis algorithms for digital mammography. ROC data on cases completed to date (Appendix IV) have shown that the case selection

reflects adequate range of subtlety.

b. Develop and evaluate improved interactive grayscale workstation display protocols.

c. Utilize the jackknife ROC analysis on a database of proven images and patient data.

d. Evaluate and correlate the type and subtlety of breast lesions versus reader responses on digital and analog images.

e. Evaluate image compression ratios for ROC metrics.

Our first year of ROC analysis for 200 normals and and 200 abnormals of digitized screen-films has reinforced the need for implementing other methods for evaluating reader responses. ROC analysis is very time consuming, often requiring convincing mammographers to participate in such studies. It is often suggested that qualified mammographers can read 200 to 300 cases per day for ROC studies. The existing database of 200 normals and 200 abnormals will serve as a resource for those researchers engaged in

evaluating reader analysis.

We have just begun our studies on the use of the ratio of throughput/cost as a means of evaluating cost of telemammography. Throughput (jobs/second) is a production measure used in evaluating computer networks. As the throughput increases in a telemammography system, the cost will increase linearly until a bottleneck is reached. Then the throughput can only increase by spending additional resources to alter the bottlenecks.

Studies are badly needed in determining the optimum image compression ratio for use in telemammography systems. Our initial evaluation is suggesting the use of wavelet algorithms at 50 to 1. Such studies require ROC studies to be accepted by the Radiology profession. A 30 to 1 compression ratio means that a single digital channel (DS-0, 64K bits/sec) can be used to transmitt digital mammography images at less than a minute. Such a compression ratio will also significantly reduce the amount of storage media for long-term storage.

## 3.2 Recommended Changes

Upon completion of our first year of studying telemammography systems, we have several recommended changes.

First, the jackknife methodology for

conducting ROC analysis should be the method of choice. This method involves the analysis of variance (ANOVA) of the pseudovalues computed by the Quencville-Tikey version of the jackknife. This experimental design permits the comparison of multiple treatments, defined in our study as analog screen-film cases (treatment 1) and grayscale displayed cases (treatment 2).

Second, the statistical power obtained is significant when we have 200 normals and 200 abnormals and with 10 readers. The cases have been carefully selectd and the 10 readers are qualified mammographers. We have learned that completion of this number of cases by all readers is very difficult to accomplish. The readers are not often available when they are needed. The number of cases (400) creates a management difficulty. It may be that 100 normals and 100 abnormals would be better with the use of 15 readers.

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# APPENDIX I

| CASE # | PARENCHYMAL | GROUP | FINDINGS | DIAGNOSIS |
|---|---|---|---|---|
| 001 | 3 | NORMAL | | |
| 002 | 2 | NORMAL | | |
| 003 | 3 | ABN | CA, AD, FAD | M |
| 004 | 3 | ABN | CA | B |
| 005 | 3 | ABN | CA | M |
| 006 | 4 | ABN | CA | B |
| 007 | 4 | ABN | MASS | B |
| 008 | 3 | ABN | CA | B |
| 009 | 1 | NORMAL | | |
| 010 | 2 | NORMAL | | |
| 011 | 1 | NORMAL | | |
| 012 | 2 | ABN | MASS | M |
| 013 | 1 | ABN | AD, MASS | M |
| 014 | 2 | ABN | CA | M |
| 015 | 3 | NORMAL | | |
| 016 | 4 | NORMAL | | |
| 017 | 1 | ABN | MASS | B |
| 018 | 2 | ABN | CA | M |
| 019 | 2 | ABN | CA | M |
| 020 | 1 | ABN | MASS | M |
| 021 | 2 | NORMAL | | |
| 022 | 4 | NORMAL | | |
| 023 | 2 | ABN | FAD | B |
| 024 | 3 | ABN | FAD | B |
| 025 | 2 | NORMAL | | |
| 026 | 1 | NORMAL | | |
| 027 | 4 | ABN | CA | B |
| 028 | 1 | NORMAL | | |
| 029 | 1 | ABN | MASS | B |
| 030 | 1 | ABN | MASS | B |
| 031 | 3 | NORMAL | | |
| 032 | 3 | ABN | FAD | B |
| 033 | 1 | ABN | CA | B |
| 034 | 2 | NORMAL | | |
| 035 | 4 | NORMAL | | |
| 036 | 2 | ABN | FAD | B |
| 037 | 3 | ABN | CA | B |
| 038 | 3 | NORMAL | | |
| 039 | 2 | NORMAL | | |
| 040 | 4 | ABN | CA | B |

| | | | | |
|---|---|---|---|---|
| 041 | 4 | ABN | CA | B |
| 042 | 2 | NORMAL | | |
| 043 | 4 | NORMAL | | |
| 044 | 2 | NORMAL | | |
| 045 | 3 | ABN | FAD | M |
| 046 | 4 | NORMAL | | |
| 047 | 3 | NORMAL | | |
| 048 | 2 | NORMAL | | |
| 049 | 4 | NORMAL | | |
| 050 | 2 | NORMAL | | |
| 051 | 2 | ABN | CA | B |
| 052 | 3 | NORMAL | | |
| 053 | 1 | NORMAL | | |
| 054 | 1 | NORMAL | | |
| 055 | 1 | ABN | MASS | B |
| 056 | 1 | ABN | CA | B |
| 057 | 1 | ABN | MASS | B |
| 058 | 2 | NORMAL | | |
| 059 | 4 | NORMAL | | |
| 060 | 1 | NORMAL | | |
| 061 | 4 | ABN | CA | B |
| 062 | 2 | NORMAL | | |
| 063 | 1 | NORMAL | | |
| 064 | 3 | NORMAL | | |
| 065 | 1 | ABN | MASS | B |
| 066 | 3 | NORMAL | | |
| 067 | 4 | NORMAL | | |
| 068 | 3 | ABN | CA | M |
| 069 | 3 | ABN | MASS | B |
| 070 | 3 | NORMAL | | |
| 071 | 3 | ABN | CA | B |
| 072 | 3 | ABN | CA | M |
| 073 | 1 | NORMAL | | |
| 074 | 2 | ABN | CA | M |
| 075 | 1 | NORMAL | | |
| 076 | 4 | NORMAL | | |
| 077 | 4 | NORMAL | | |
| 078 | 3 | ABN | MASS | B |
| 079 | 2 | ABN | MASS | B |
| 080 | 2 | ABN | MASS | M |
| 081 | 3 | ABN | CA | M |
| 082 | 3 | ABN | CA | B |
| 083 | 1 | NORMAL | | |
| 084 | 2 | NORMAL | | |
| 085 | 1 | NORMAL | | |

| | | | | |
|---|---|---|---|---|
| 086 | 3 | ABN | MASS | M |
| 087 | 3 | ABN | CA | M |
| 088 | 1 | ABN | CA | B |
| 089 | 3 | ABN | FAD | B |
| 090 | 3 | ABN | MASS | B |
| 091 | 4 | ABN | CA | M |
| 092 | 3 | NORMAL | | |
| 093 | 1 | NORMAL | | |
| 094 | 1 | ABN | MASS, CA | M |
| 095 | 1 | ABN | MASS | M |
| 096 | 4 | NORMAL | | |
| 097 | 4 | NORMAL | | |
| 098 | 1 | NORMAL | | |
| 099 | 4 | NORMAL | | |
| 100 | 3 | ABN | MASS | M |
| 101 | 3 | NORMAL | | |
| 102 | 3 | ABN | AD | M |
| 103 | 4 | ABN | CA | M |
| 104 | 1 | ABN | MASS | M |
| 105 | 3 | NORMAL | | |
| 106 | 2 | ABN | MASS | B |
| 107 | 1 | NORMAL | | |
| 108 | 2 | ABN | AD | M |
| 109 | 4 | ABN | CA | M |
| 110 | 1 | NORMAL | | |
| 111 | 3 | ABN | FAD | M |
| 112 | 2 | NORMAL | | |
| 113 | 3 | ABN | FAD | M |
| 114 | 3 | ABN | CA | M |
| 115 | 2 | NORMAL | | |
| 116 | 2 | NORMAL | | |
| 117 | 1 | NORMAL | | |
| 118 | 1 | ABN | MASS | B |
| 119 | 4 | NORMAL | | |
| 120 | 1 | NORMAL | | |
| 121 | 3 | NORMAL | | |
| 122 | 4 | NORMAL | | |
| 123 | 4 | ABN | CA | B |
| 124 | 1 | ABN | CA | M |
| 125 | 3 | ABN | CA | B |
| 126 | 1 | ABN | FAD | B |
| 127 | 4 | NORMAL | | |
| 128 | 2 | ABN | CA | B |
| 129 | 4 | ABN | CA | M |
| 130 | 1 | NORMAL | | |

| | | | | |
|---|---|---|---|---|
| 131 | 3 | NORMAL | | |
| 132 | 3 | ABN | CA | B |
| 133 | 1 | ABN | CA | M |
| 134 | 1 | ABN | CA | B |
| 135 | 2 | NORMAL | | |
| 136 | 3 | NORMAL | | |
| 137 | 2 | NORMAL | | |
| 138 | 3 | ABN | MASS | M |
| 139 | 2 | ABN | FAD | M |
| 140 | 3 | NORMAL | | |
| 141 | 1 | NORMAL | | |
| 142 | 3 | ABN | MASS | M |
| 143 | 4 | ABN | MASS | M |
| 144 | 3 | ABN | CA | B |
| 145 | 4 | NORMAL | | |
| 146 | 1 | ABN | MASS | M |
| 147 | 1 | NORMAL | | |
| 148 | 2 | NORMAL | | |
| 149 | 4 | NORMAL | | |
| 150 | 3 | NORMAL | | |
| 151 | 1 | ABN | MASS | B |
| 152 | 4 | NORMAL | | |
| 153 | 1 | ABN | MASS | M |
| 154 | 4 | NORMAL | | |
| 155 | 3 | NORMAL | | |
| 156 | 2 | ABN | | B |
| 157 | 3 | NORMAL | | |
| 158 | 4 | NORMAL | | |
| 159 | 4 | NORMAL | | |
| 160 | 3 | ABN | | M |
| 161 | 2 | ABN | CA | B |
| 162 | 2 | NORMAL | | |
| 163 | 3 | ABN | | B |
| 164 | 3 | ABN | AD | M |
| 165 | 2 | NORMAL | | |
| 166 | 1 | ABN | FAD | M |
| 167 | 4 | NORMAL | | |
| 168 | 4 | ABN | | B |
| 169 | 4 | ABN | CA | B |
| 170 | 1 | ABN | MASS | M |
| 171 | 3 | NORMAL | | |
| 172 | 2 | NORMAL | | |
| 173 | 3 | NORMAL | | |
| 174 | 4 | ABN | | B |
| 175 | 4 | ABN | MASS | M |

| | | | | |
|---|---|---|---|---|
| 176 | 4 | NORMAL | | |
| 177 | 1 | NORMAL | | |
| 178 | 3 | ABN | FCC | B |
| 179 | 2 | ABN | CA | B |
| 180 | 4 | NORMAL | | |
| 181 | 2 | ABN | MASS | B |
| 182 | 4 | NORMAL | | |
| 183 | 2 | NORMAL | | |
| 184 | 3 | NORMAL | | |
| 185 | 1 | NORMAL | | |
| 186 | 1 | ABN | CA | B |
| 187 | 3 | ABN | MASS | M |
| 188 | 3 | ABN | MASS | M |
| 189 | 4 | NORMAL | | |
| 190 | 2 | NORMAL | | |
| 191 | 3 | ABN | CA | B |
| 192 | 4 | ABN | CA | M |
| 193 | 3 | NORMAL | | |
| 194 | 3 | ABN | | M |
| 195 | 3 | ABN | MASS | M |
| 196 | 2 | ABN | MASS | M |
| 197 | 1 | NORMAL | | |
| 198 | 2 | NORMAL | | |
| 199 | 3 | NORMAL | | |
| 200 | 3 | ABN | MASS, CA | M |
| 201 | 2 | NORMAL | | |
| 202 | 1 | ABN | | M |
| 203 | 2 | NORMAL | | |
| 204 | 3 | NORMAL | | |
| 205 | 2 | ABN | | M |
| 206 | 2 | ABN | | B |
| 207 | 3 | NORMAL | | |
| 208 | 4 | ABN | MASS | B |
| 209 | 3 | NORMAL | | |
| 210 | 2 | ABN | CA | M |
| 211 | 1 | NORMAL | | |
| 212 | 4 | ABN | | M |
| 213 | 4 | NORMAL | | |
| 214 | 4 | ABN | CA | M |
| 215 | 1 | NORMAL | | |
| 216 | 4 | ABN | CA | M |
| 217 | 2 | NORMAL | | |
| 218 | 4 | NORMAL | | |
| 219 | 3 | ABN | CA | M |
| 220 | 1 | NORMAL | | |

| | | | | |
|---|---|---|---|---|
| 221 | 3 | NORMAL | | |
| 222 | 3 | ABN | | M |
| 223 | 1 | NORMAL | | |
| 224 | 1 | NORMAL | | |
| 225 | 1 | NORMAL | | |
| 226 | 1 | NORMAL | | |
| 227 | 3 | NORMAL | | |
| 228 | 3 | ABN | CA | M |
| 229 | 1 | NORMAL | | |
| 230 | 3 | ABN | FAD | B |
| 231 | 3 | ABN | MASS | M |
| 232 | 4 | NORMAL | | |
| 233 | 3 | ABN | MASS | M |
| 234 | 3 | ABN | AD | B |
| 235 | 1 | NORMAL | | |
| 236 | 1 | NORMAL | | |
| 237 | 4 | ABN | CA | M |
| 238 | 1 | ABN | CA | M |
| 239 | 2 | NORMAL | | |
| 240 | 1 | NORMAL | | |
| 241 | 2 | ABN | | M |
| 242 | 3 | NORMAL | | |
| 243 | 1 | ABN | MASS | M |
| 244 | 2 | ABN | MASS | M |
| 245 | 3 | NORMAL | | |
| 246 | 4 | ABN | | B |
| 247 | 4 | ABN | CA | B |
| 248 | 1 | ABN | | B |
| 249 | 2 | ABN | CA | M |
| 250 | 1 | ABN | CA | B |
| 251 | 3 | ABN | MASS | M |
| 252 | 3 | NORMAL | | |
| 253 | 2 | ABN | MASS | M |
| 254 | 1 | ABN | CA | M |
| 255 | 4 | NORMAL | | |
| 256 | 4 | NORMAL | | |
| 257 | 2 | ABN | CA | M |
| 258 | 1 | NORMAL | | |
| 259 | 2 | ABN | MASS | B |
| 260 | 4 | NORMAL | | |
| 261 | 3 | ABN | CA | B |
| 262 | 2 | NORMAL | | |
| 263 | 1 | ABN | MASS | M |
| 264 | 1 | ABN | CA | B |
| 265 | 4 | ABN | CA | M |

| | | | | |
|---|---|---|---|---|
| 266 | 2 | NORMAL | | |
| 267 | 1 | NORMAL | | |
| 268 | 1 | ABN | FAD | B |
| 269 | 2 | NORMAL | | |
| 270 | 2 | ABN | CA | M |
| 271 | 3 | ABN | CA | M |
| 272 | 4 | NORMAL | | |
| 273 | 3 | ABN | CA | M |
| 274 | 3 | NORMAL | | |
| 275 | 2 | ABN | CA | M |
| 276 | 4 | ABN | CA | M |
| 277 | 2 | NORMAL | | |
| 278 | 4 | NORMAL | | |
| 279 | 3 | NORMAL | | |
| 280 | 1 | NORMAL | | |
| 281 | 3 | NORMAL | | |
| 282 | 3 | ABN | CA | B |
| 283 | 4 | ABN | CA | M |
| 284 | 4 | ABN | CA | M |
| 285 | 3 | NORMAL | | |
| 286 | 2 | NORMAL | | |
| 287 | 1 | ABN | MASS | M |
| 288 | 4 | ABN | CA | M |
| 289 | 3 | NORMAL | | |
| 290 | 1 | ABN | MASS | M |
| 291 | 2 | NORMAL | | |
| 292 | 3 | NORMAL | | |
| 293 | 3 | ABN | CA | M |
| 294 | 4 | NORMAL | | |
| 295 | 3 | ABN | CA | B |
| 296 | 3 | ABN | MASS | B |
| 297 | 2 | NORMAL | | |
| 298 | 4 | NORMAL | | |
| 299 | 3 | ABN | CA | M |
| 300 | 1 | NORMAL | | |
| 301 | 4 | ABN | CA | M |
| 302 | 4 | NORMAL | | |
| 303 | 4 | NORMAL | | |
| 304 | 3 | ABN | CA | M |
| 305 | 3 | ABN | CA | B |
| 306 | 2 | ABN | MASS | B |
| 307 | 4 | NORMAL | | |
| 308 | 4 | ABN | FAD | M |
| 309 | 1 | ABN | MASS | M |
| 310 | 4 | NORMAL | | |

| | | | | |
|---|---|---|---|---|
| 311 | 4 | ABN | FAD | M |
| 312 | 2 | ABN | MASS | M |
| 313 | 3 | NORMAL | | |
| 314 | 3 | ABN | CA | M |
| 315 | 4 | NORMAL | | |
| 316 | 2 | ABN | MASS | M |
| 317 | 2 | NORMAL | | |
| 318 | 4 | NORMAL | | |
| 319 | 3 | NORMAL | | |
| 320 | 3 | ABN | CA | B |
| 321 | 4 | NORMAL | | |
| 322 | 2 | ABN | CA | M |
| 323 | 4 | ABN | CA | M |
| 324 | 4 | ABN | CA | B |
| 325 | 2 | ABN | FAD | B |
| 326 | 3 | NORMAL | | |
| 327 | 2 | NORMAL | | |
| 328 | 3 | ABN | CA | B |
| 329 | 2 | NORMAL | | |
| 330 | 2 | ABN | MASS | B |
| 331 | 2 | NORMAL | | |
| 332 | 1 | NORMAL | | |
| 333 | 4 | ABN | MASS | M |
| 334 | 2 | ABN | FAD | M |
| 335 | 1 | ABN | MASS | M |
| 336 | 2 | ABN | MASS | M |
| 337 | 2 | ABN | CA | B |
| 338 | 2 | NORMAL | | |
| 339 | 3 | NORMAL | | |
| 340 | 2 | NORMAL | | |
| 341 | 3 | ABN | CA | M |
| 342 | 3 | NORMAL | | |
| 343 | 3 | NORMAL | | |
| 344 | 2 | NORMAL | | |
| 345 | 2 | NORMAL | | |
| 346 | 3 | ABN | CA | M |
| 347 | 2 | NORMAL | | |
| 348 | 2 | ABN | MASS | B |
| 349 | 2 | NORMAL | | |
| 350 | 2 | NORMAL | | |

# KEY

PARENCHYMAL DENSITY:
1=FATTY
2=SCATTERED FIBROGLANDULAR TISSUE
3=HETEROGENEOUSLY DENSE
4= EXTREMELY DENSE

GROUP:

NORMAL=NORMAL
ABN = ABNORMAL

FINDINGS:

MASS=MASS
FAD =FOCAL ASYMMETRIC DENSITY
AD =ARCHITECTURAL DISTORTION
CA =CALCIFICATIONS

DIAGNOSIS:

M=MALIGNANT
B=BENIGN

# APPENDIX II A

**READERS RESPONSES TO CASE 84**

| MASS | CALCIFICATION | FAD/AD | DIAGNOSIS | READER # |
|---|---|---|---|---|
| 1 | 5 | 1 | 3 | 6 |
| 2 | 5 | 1 | 2 | 5 |
| 2 | 2 | 1 | 1 | 4 |
| 1 | 5 | 1 | 4 | 3 |
| 1 | 1 | 2 | 2 | 2 |
| 1 | 2 | 1 | 2 | 7 |
| 1 | 5 | 1 | 4 | 10 |
| 1 | 5 | 1 | 3 | 11 |

**KEY TO FINDINGS:**

1=DEFINITELY NOT PRESENT

2=PROBABLY NOT PRESENT

3=EQUIVOCAL

4=PROBABLY PRESENT

5=DEFINITELY PRESENT

**KEY TO DIAGNOSIS**

1=DEFINITELY BENIGN

2=PROBABLY BENIGN

3=EQUIVOCAL

4=PROBABLY MALIGNANT

5=DEFINITLEY MALIGNANT

# APPENDIX II B

**READERS SPECIFIC RESPONSES**

**READER 6**

| | TRUE NORMALS (149) | TRUE BENIGN (66) | TRUE MALIGNANT (84) |
|---|---|---|---|
| DEFINITELY BENIGN | 010 | 01 | 00 |
| PROBABLY BENIGN | 121 | 17 | 14 |
| EQUIVOCAL | 017 | 41 | 30 |
| PROBABLY MALIGNANT | 001 | 07 | 25 |
| DEFINITELY MALIGNANT | 000 | 00 | 15 |

**READER 2**

| | TRUE NORMALS (149) | TRUE BENIGN (66) | TRUE MALIGNANT (84) |
|---|---|---|---|
| DEFINITELY BENIGN | 28 | 02 | 01 |
| PROBABLY BENIGN | 62 | 17 | 06 |
| EQUIVOCAL | 59 | 37 | 41 |
| PROBABLY MALIGNANT | 00 | 10 | 23 |
| DEFINITELY MALIGNANT | 00 | 00 | 13 |

# APPENDIX III A

## CLINICAL HISTORY SHEET

**MAMMOGRAPHY CLINICAL HISTORY SHEET**

HISTORY NO.: _____ DATE OF SERVICE: _____

NAME: LAST _____ FIRST _____ M.I. _____

ADDRESS: _____ ZIP: _____

SSN: _____ DATE OF BIRTH: _____

HOME PHONE NUMBER: (___) ____-_____ WORK PHONE: (___) ____-_____

==========

**IS THIS YOUR FIRST MAMMOGRAM?** **Y** **N**

IF NO, WHERE WERE YOUR OLD FILMS DONE? _____

WHEN WAS YOUR LAST MAMMOGRAM? _____

HOW OLD WERE YOU WHEN YOUR PERIOD STARTED? _____

WHAT IS THE DATE OF YOUR LAST PERIOD? _____

HAVE YOU EVER HAD A HYSTERECTOMY? Y N

DID THEY REMOVE YOUR OVARIES? Y N

HOW MANY TIMES HAVE YOU BEEN PREGNANT? _____

HOW MANY CHILDREN DO YOU HAVE? _____

HOW OLD WERE YOU WHEN YOUR FIRST CHILD WAS BORN? _____

DO YOU TAKE BIRTH CONTROL PILLS? _____

**HAVE YOU EVER HAD CANCER?** **Y** **N**

IF YES, WHAT KIND OF CANCER? _____

HAVE ANY OF YOUR FAMILY MEMBERS HAD BREAST CANCER?

MOTHER___ SISTER___ AUNT___ GRANDMOTHER___ OTHER___

GIVE AGE AT DIAGNOSIS: _____

**DO YOU HAVE BREAST IMPLANTS?** **Y** **N**

IF YES, WHAT KIND OF IMPLANTS? _____

DO YOU TAKE HORMONES? Y N

WHAT KIND OF HORMONES? ESTROGEN____ TAMOXIFIN___

PROGESTERONE___ OTHER_____

AT WHAT AGE DID YOU BEGIN TAKING HORMONES? _____

**HAVE YOU EVER HAD BREAST SURGERY?** **Y** **N**

IF YES, WHEN AND WHICH BREAST? _____

WHAT WERE THE RESULTS? _____

**HAVE YOU EVER HAD RADIATION THERAPY?** **Y** **N**

IF YES, WHICH BREAST AND IN WHAT YEAR? _____

**HAVE YOU EVER HAD A BREAST REMOVED?** **Y** **N**

IF YES, WHICH BREAST? _____

**HAVE YOU FOUND ANY NEW LUMPS IN YOUR BREAST?** **Y** **N**

IF YES, WHICH BREAST? _____

HOW LONG HAVE YOU HAD THE LUMP? _____

HAS THE LUMP CHANGED? _____

**DO YOU HAVE ANY OTHER NEW BREAST PROBLEMS?** **Y** **N**

IF YES, PLEASE DESCRIBE: _____

WHEN DID THE PROBLEM START? _____

TECH ID:_____

CLINICAL FINDINGS:

SCREENING___ FOLLOW UP AT SHORT INTERVAL__

ADDITIONAL VIEWS___

REVIEW OF OUTSIDE STUDY___ PRE-RADIATION THERAPY___

PROBLEMS INDICATED:

PALPABLE ABNORMALITY___ BLOODY DISCHARGE___

NON BLOODY DISCHARGE___ BREAST IMPLANT PROBLEM___

SKIN THICKENING OR RETRACTION___ NIPPLE ABNORMALITY___

PAIN___ CANCER ELSEWHERE___ LARGE AXILLARY LYMPH NODES___

OTHER_____

ANGLE OF OBLIQUITY ON MLO: 30 45 60

BREAST ULTRASOUND: (PLEASE CIRCLE)

RIGHT LEFT BOTH

ADDITIONAL VIEWS: (PLEASE INDICATE WHICH BREAST R OR L)

1)_____ 2)_____

3)_____ 4)_____

PLEASE CIRCLE MACHINE USED:

NELSON CLINIC STONY POINT

I II III IV I II

| VIEW | MAS | KVP | + OR - | KG | MM |
|---|---|---|---|---|---|
| R CC | | | | | |
| L CC | | | | | |
| R MLO | | | | | |
| L MLO | | | | | |

COMMENTS:_____

# APPENDIX III B

## MAMMOGRAPHIC FINDINGS

acri AMERICAN COLLEGE OF RADIOLOGY INSTITUTE

MagView™

# Finding check-off sheets

Patient ID: _____

Patient Name: _____

Examination Date: _____

☐ Prior study dates compared: __/__/____ __/__/____ __/__/____

Finding# _____ of _____

## ☐ Negative exam

- ☐ Mammogram
- ☐ Ultrasound
- ☐ Ductography

Tissue Density
- ☐ Almost entirely fat
- ☐ Scattered fibroglandular densities
- ☐ Heterogeneously dense
- ☐ Extremely dense

Recommendation
- ☐ Normal interval screening in____ months or by age____.
- ☐ Any decision to biopsy should be based on clinical assessment

Initials:_____

## ☐ Non-Negative Finding

☐ Finding correlates to clinical exam finding in ☐L ☐R ☐B breast(s) at _____ (location)

☐ Follow-up
- ☐ Follow-up of procedure
  - ☐ Lumpectomy
  - ☐ Excisional biopsy
  - ☐ Mastectomy
  - ☐ Needle biopsy
  - ☐ Radiation Therapy

☐ Follow-up of prior finding in ☐L ☐R ☐B breast(s) at _____ (location).

☐ Change
- ☐ No significant changes
- ☐ Increase in size
- ☐ Decrease in size
- ☐ Increase in number of calcifications
- ☐ Decrease in number of calcifications
- ☐ Less defined
- ☐ More defined
- ☐ Completely removed
- ☐ Partially removed

## Finding Side:

☐ Left ☐ Right ☐ Both ☐ Multiple similar findings: Approximate number:_____

## Mammogram

☐ Not seen on mammogram

Tissue Density (choose one)
- ☐ Almost entirely fat
- ☐ Scattered fibroglandular densities
- ☐ Heterogeneously dense
- ☐ Extremely dense

Mass Shape (choose one)
- ☐ Round
- ☐ Oval
- ☐ Lobular
- ☐ Irregular
- ☐ Architectural distortion
- ☐ Tubular density/solitary dilated duct
- ☐ Intramammary lymph node
- ☐ Asymmetric breast tissue
- ☐ Focal asymmetric density

Margins (choose one)
- ☐ Circumscribed
- ☐ Microlobulated
- ☐ Obscured
- ☐ Indistinct
- ☐ Spiculated

Density (choose one)
- ☐ High density
- ☐ Low density
- ☐ Isodense
- ☐ Fat containing

Calcifications
- ☐ Skin
- ☐ Vascular
- ☐ Coarse
- ☐ Large rod-like
- ☐ Large round
- ☐ Eggshell or rim
- ☐ Milk of calcium
- ☐ Dystrophic
- ☐ Punctate
- ☐ Amorphous or indistinct
- ☐ Heterogeneous or pleomorphic
- ☐ Fine and/or branching
- ☐ Spherical or lucent-centered
- ☐ Suture

Distribution (choose one)
- ☐ Grouped or clustered
- ☐ Segmental
- ☐ Regional
- ☐ Linear
- ☐ Diffuse/scattered

Other findings
- ☐ Nipple retraction
- ☐ Skin thickening
- ☐ Trabecular thickening
- ☐ Skin lesion
- ☐ Axilliary adenopathy
- ☐ Skin retraction
- ☐ Architectural distortion
- ☐ Hematoma
- ☐ Post surgical scar

Implant Findings
- ☐ Asymmetric implant
- ☐ Calcified implant
- ☐ Distorted implant
- ☐ Fibrosed implant
- ☐ Herniated implant
- ☐ Ruptured implant
- ☐ Free silicone
- ☐ Capsular contraction

## Ductography

- ❑ Not seen on Ductogram
- ❑ Intraluminal filling defect
- ❑ Duct ectasia
- ❑ Multiple filling defects
- ❑ Abrupt duct termination
- ❑ Extravasation
- ❑ Duct narrowing
- ❑ Cyst fill

## Ultrasound

- ❑ Not seen on Ultrasound

**Modifiers**

- ❑ Anechoic
- ❑ Hypoechoic
- ❑ Hyperechoic
- ❑ Isoechoic
- ❑ Mixed echogenicity
- ❑ Posterior acoustic shadowing
- ❑ Posterior acoustic enhancement

**Finding**

- ❑ Simple cyst
- ❑ Complex Cyst
- ❑ Intracystic lesion
- ❑ Duct ectasia
- ❑ Solid mass

## Size and Location

Size _____millimeters

Location _____o'clock

- ❑ Subareolar
- ❑ Central
- ❑ Axillary tail

**Depth**

- ❑ Anterior
- ❑ Middle
- ❑ Posterior

## Assessment and Recommendation

**Additional Evaluation Needed**

- ❑ Cyst aspiration
- ❑ Additional projections
- ❑ Magnification views
- ❑ Spot compression
- ❑ Clinical correlation
- ❑ Ultrasound exam

**Benign**

- ❑ Normal interval screening in _____ months
- ❑ Cyst aspiration
- ❑ Any decision to biopsy should be based on clinical assessment

**Probably Benign**

- ❑ Short interval follow-up in _____ months

**Suspicious**

- ❑ Biopsy should be considered
- ❑ Needle localization and biop
- ❑ Histology using core biopsy

**Malignant**

- ❑ Biopsy should be considered
- ❑ Needle localization and biop
- ❑ Histology using core biopsy
- ❑ Appropriate action should be taken

## Notes



Initials:_____

# APPENDIX IV A

## READER STATUS REPORT

| READER | CASES READ ( AS OF 09-30-95) |
|---|---|
| 02 | 1-299 |
| 03 | 1-299 |
| 04 | 1-299 |
| 05 | 1-350 |
| 06 | 1-300 |
| 07 | 1-300 |
| 09 | 1-250 |
| 10 | 1-200 |
| 11 | 1-200 |
| 12 | 1-100 |
| 13 | 1-100 |

# APPENDIX IV B

## ROC RESULTS OF READERS FOR ANALOG IMAGES

# APPENDIX IV

# B I

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 2, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 59.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 44. | 44. | 53. | 2. | 6. |
| ACTUALLY POSITIVE CASES | 3. | 3. | 8. | 10. | 35. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0403 0.0537 0.4094 0.7047 1.0000
TPF: 0.0000 0.5932 0.7627 0.8983 0.9492 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.3744 B= 0.5371
Z(K)= -0.5376 0.2287 1.6104 1.7480
LOGL= -271.0403
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.4609 B= 0.6171
Z(K)= -0.5266 0.2289 1.4998 1.9286
LOGL= -264.3502
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0525 | 0.0197 | 0.0050 | 0.0052 | 0.0045 | 0.0009 |
| B | 0.0197 | 0.0173 | 0.0020 | 0.0011 | -0.0052 | -0.0117 |
| Z( 1) | 0.0050 | 0.0020 | 0.0116 | 0.0062 | 0.0030 | 0.0021 |
| Z( 2) | 0.0052 | 0.0011 | 0.0062 | 0.0105 | 0.0055 | 0.0047 |
| Z( 3) | 0.0045 | -0.0052 | 0.0030 | 0.0055 | 0.0234 | 0.0231 |
| Z( 4) | 0.0009 | -0.0117 | 0.0021 | 0.0047 | 0.0231 | 0.0397 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.6523 | 0.2014 | 0.2210 | 0.1284 | 0.0187 |
| B | 0.6523 | 1.0000 | 0.1390 | 0.0823 | -0.2592 | -0.4476 |
| Z( 1) | 0.2014 | 0.1390 | 1.0000 | 0.5645 | 0.1807 | 0.0962 |
| Z( 2) | 0.2210 | 0.0823 | 0.5645 | 1.0000 | 0.3543 | 0.2323 |
| Z( 3) | 0.1284 | -0.2592 | 0.1807 | 0.3543 | 1.0000 | 0.7586 |
| Z( 4) | 0.0187 | -0.4476 | 0.0962 | 0.2323 | 0.7586 | 1.0000 |

AREA = 0.8931 STD. DEV.(AREA) = 0.0290

1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.4487 | ( 0.2635 | , | 0.6460 ) |
| 0.010 | 0.5100 | ( 0.3324 | , | 0.6855 ) |
| 0.020 | 0.5766 | ( 0.4124 | , | 0.7283 ) |
| 0.030 | 0.6179 | ( 0.4638 | , | 0.7551 ) |
| 0.040 | 0.6481 | ( 0.5019 | , | 0.7751 ) |
| 0.050 | 0.6721 | ( 0.5322 | , | 0.7911 ) |
| 0.060 | 0.6919 | ( 0.5573 | , | 0.8046 ) |
| 0.070 | 0.7088 | ( 0.5787 | , | 0.8163 ) |
| 0.080 | 0.7236 | ( 0.5973 | , | 0.8266 ) |
| 0.090 | 0.7367 | ( 0.6137 | , | 0.8359 ) |
| 0.100 | 0.7485 | ( 0.6284 | , | 0.8443 ) |
| 0.110 | 0.7592 | ( 0.6416 | , | 0.8520 ) |
| 0.120 | 0.7690 | ( 0.6537 | , | 0.8591 ) |
| 0.130 | 0.7781 | ( 0.6647 | , | 0.8656 ) |
| 0.140 | 0.7865 | ( 0.6749 | , | 0.8718 ) |
| 0.150 | 0.7943 | ( 0.6844 | , | 0.8775 ) |
| 0.200 | 0.8268 | ( 0.7234 | , | 0.9015 ) |
| 0.250 | 0.8520 | ( 0.7531 | , | 0.9200 ) |
| 0.300 | 0.8723 | ( 0.7771 | , | 0.9348 ) |
| 0.400 | 0.9040 | ( 0.8147 | , | 0.9568 ) |
| 0.500 | 0.9280 | ( 0.8442 | , | 0.9719 ) |
| 0.600 | 0.9471 | ( 0.8693 | , | 0.9826 ) |
| 0.700 | 0.9628 | ( 0.8921 | , | 0.9901 ) |
| 0.800 | 0.9762 | ( 0.9142 | , | 0.9952 ) |
| 0.900 | 0.9878 | ( 0.9384 | , | 0.9985 ) |
| 0.950 | 0.9934 | ( 0.9538 | , | 0.9995 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0269, 0.6067) | (0.0102, 0.5118) | (0.0620, 0.6956) |
| (0.0668, 0.7038) | (0.0360, 0.6369) | (0.1151, 0.7644) |
| (0.4095, 0.9065) | (0.3338, 0.8841) | (0.4887, 0.9256) |
| (0.7008, 0.9629) | (0.6238, 0.9511) | (0.7696, 0.9723) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 2, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 82.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 127. | 14. | 5. | 0. | 3. |
| ACTUALLY POSITIVE CASES | 12. | 6. | 4. | 11. | 49. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0201 0.0201 0.0537 0.1477 1.0000

TPF: 0.0000 0.5976 0.7317 0.7805 0.8537 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.8080 B= 0.6820
Z(K)= 1.0466 1.6104 1.9514 2.0514
LOGL= -191.9226
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.8169 B= 0.6938
Z(K)= 1.0526 1.5531 1.8560 2.2459
LOGL= -184.4330
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.1216 | 0.0618 | 0.0150 | 0.0032 | -0.0095 | -0.0326 |
| B | 0.0618 | 0.0410 | 0.0038 | -0.0066 | -0.0169 | -0.0348 |
| Z( 1) | 0.0150 | 0.0038 | 0.0159 | 0.0128 | 0.0112 | 0.0092 |
| Z( 2) | 0.0032 | -0.0066 | 0.0128 | 0.0233 | 0.0235 | 0.0254 |
| Z( 3) | -0.0095 | -0.0169 | 0.0112 | 0.0235 | 0.0350 | 0.0406 |
| Z( 4) | -0.0326 | -0.0348 | 0.0092 | 0.0254 | 0.0406 | 0.0667 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.8756 | 0.3411 | 0.0600 | -0.1452 | -0.3622 |
| B | 0.8756 | 1.0000 | 0.1502 | -0.2124 | -0.4452 | -0.6656 |
| Z( 1) | 0.3411 | 0.1502 | 1.0000 | 0.6645 | 0.4752 | 0.2833 |
| Z( 2) | 0.0600 | -0.2124 | 0.6645 | 1.0000 | 0.8240 | 0.6448 |
| Z( 3) | -0.1452 | -0.4452 | 0.4752 | 0.8240 | 1.0000 | 0.8409 |
| Z( 4) | -0.3622 | -0.6656 | 0.2833 | 0.6448 | 0.8409 | 1.0000 |

AREA = 0.9323 STD. DEV.(AREA) = 0.0231

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.5118 | ( 0.3057 , | 0.7147 ) |
| 0.010 | 0.5803 | ( 0.3971 , | 0.7473 ) |
| 0.020 | 0.6524 | ( 0.4987 , | 0.7843 ) |
| 0.030 | 0.6956 | ( 0.5595 , | 0.8089 ) |
| 0.040 | 0.7264 | ( 0.6018 , | 0.8279 ) |
| 0.050 | 0.7503 | ( 0.6334 , | 0.8438 ) |
| 0.060 | 0.7697 | ( 0.6581 , | 0.8574 ) |
| 0.070 | 0.7861 | ( 0.6781 , | 0.8693 ) |
| 0.080 | 0.8001 | ( 0.6947 , | 0.8799 ) |
| 0.090 | 0.8123 | ( 0.7088 , | 0.8894 ) |
| 0.100 | 0.8232 | ( 0.7209 , | 0.8979 ) |
| 0.110 | 0.8329 | ( 0.7315 , | 0.9056 ) |
| 0.120 | 0.8417 | ( 0.7409 , | 0.9126 ) |
| 0.130 | 0.8498 | ( 0.7493 , | 0.9190 ) |
| 0.140 | 0.8571 | ( 0.7569 , | 0.9248 ) |
| 0.150 | 0.8639 | ( 0.7638 , | 0.9302 ) |
| 0.200 | 0.8912 | ( 0.7911 , | 0.9511 ) |
| 0.250 | 0.9114 | ( 0.8111 , | 0.9654 ) |
| 0.300 | 0.9269 | ( 0.8269 , | 0.9753 ) |

| | | | | | |
|---|---|---|---|---|---|
| 0.400 | 0.9496 | ( | 0.8517 , | 0.9874 | ) |
| 0.500 | 0.9654 | ( | 0.8715 , | 0.9938 | ) |
| 0.600 | 0.9768 | ( | 0.8887 , | 0.9972 | ) |
| 0.700 | 0.9854 | ( | 0.9047 , | 0.9989 | ) |
| 0.800 | 0.9918 | ( | 0.9210 , | 0.9997 | ) |
| 0.900 | 0.9966 | ( | 0.9395 , | 0.9999 | ) |
| 0.950 | 0.9985 | ( | 0.9519 , | 1.0000 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0124, 0.6021) | (0.0030, 0.4632) | (0.0410, 0.7291) |
| (0.0317, 0.7017) | (0.0131, 0.6083) | (0.0682, 0.7834) |
| (0.0602, 0.7702) | (0.0320, 0.7026) | (0.1049, 0.8282) |
| (0.1463, 0.8614) | (0.0968, 0.8199) | (0.2103, 0.8958) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 2, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 27.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 93. | 27. | 10. | 10. | 9. |
| ACTUALLY POSITIVE CASES | 6. | 0. | 2. | 8. | 11. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0604 0.1275 0.1946 0.3758 1.0000
TPF: 0.0000 0.4074 0.7037 0.7778 0.7778 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.3079 B= 0.8539
Z(K)= 0.3160 0.8608 1.1383 1.5517
LOGL= -209.1670
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.1742 B= 0.8234
Z(K)= 0.3269 0.8058 1.0795 1.6264
LOGL= -208.0945
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:
A 0.1161 0.0609 0.0099 0.0079 0.0057 -0.0022

| | | | | | | |
|---|---|---|---|---|---|---|
| B | 0.0609 | 0.0596 | 0.0035 | -0.0003 | -0.0037 | -0.0152 |
| Z( 1) | 0.0099 | 0.0035 | 0.0109 | 0.0082 | 0.0071 | 0.0053 |
| Z( 2) | 0.0079 | -0.0003 | 0.0082 | 0.0129 | 0.0114 | 0.0095 |
| Z( 3) | 0.0057 | -0.0037 | 0.0071 | 0.0114 | 0.0155 | 0.0134 |
| Z( 4) | -0.0022 | -0.0152 | 0.0053 | 0.0095 | 0.0134 | 0.0283 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.7313 | 0.2783 | 0.2036 | 0.1354 | -0.0388 |
| B | 0.7313 | 1.0000 | 0.1356 | -0.0097 | -0.1210 | -0.3698 |
| Z( 1) | 0.2783 | 0.1356 | 1.0000 | 0.6919 | 0.5454 | 0.3029 |
| Z( 2) | 0.2036 | -0.0097 | 0.6919 | 1.0000 | 0.8055 | 0.4983 |
| Z( 3) | 0.1354 | -0.1210 | 0.5454 | 0.8055 | 1.0000 | 0.6430 |
| Z( 4) | -0.0388 | -0.3698 | 0.3029 | 0.4983 | 0.6430 | 1.0000 |

AREA = 0.8177 STD. DEV.(AREA) = 0.0524

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1718 | ( 0.0344 , | 0.4705 ) |
| 0.010 | 0.2291 | ( 0.0648 , | 0.5128 ) |
| 0.020 | 0.3025 | ( 0.1171 , | 0.5617 ) |
| 0.030 | 0.3539 | ( 0.1613 , | 0.5946 ) |
| 0.040 | 0.3945 | ( 0.1999 , | 0.6205 ) |
| 0.050 | 0.4284 | ( 0.2341 , | 0.6422 ) |
| 0.060 | 0.4577 | ( 0.2647 , | 0.6614 ) |
| 0.070 | 0.4836 | ( 0.2924 , | 0.6786 ) |
| 0.080 | 0.5068 | ( 0.3176 , | 0.6944 ) |
| 0.090 | 0.5279 | ( 0.3407 , | 0.7091 ) |
| 0.100 | 0.5473 | ( 0.3618 , | 0.7228 ) |
| 0.110 | 0.5652 | ( 0.3813 , | 0.7357 ) |
| 0.120 | 0.5819 | ( 0.3994 , | 0.7480 ) |
| 0.130 | 0.5974 | ( 0.4162 , | 0.7596 ) |
| 0.140 | 0.6120 | ( 0.4318 , | 0.7707 ) |
| 0.150 | 0.6258 | ( 0.4464 , | 0.7812 ) |
| 0.200 | 0.6849 | ( 0.5071 , | 0.8276 ) |
| 0.250 | 0.7321 | ( 0.5534 , | 0.8652 ) |
| 0.300 | 0.7712 | ( 0.5905 , | 0.8955 ) |
| 0.400 | 0.8330 | ( 0.6483 , | 0.9396 ) |
| 0.500 | 0.8798 | ( 0.6937 , | 0.9673 ) |
| 0.600 | 0.9166 | ( 0.7329 , | 0.9840 ) |
| 0.700 | 0.9458 | ( 0.7695 , | 0.9933 ) |
| 0.800 | 0.9691 | ( 0.8068 , | 0.9979 ) |
| 0.900 | 0.9871 | ( 0.8502 , | 0.9997 ) |
| 0.950 | 0.9943 | ( 0.8798 , | 0.9999 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0519, 0.4345) | (0.0252, 0.3313) | (0.0974, 0.5424) |

(0.1402, 0.6123) (0.0929, 0.5337) (0.2016, 0.6865)
(0.2102, 0.6952) (0.1519, 0.6284) (0.2798, 0.7561)
(0.3719, 0.8173) (0.2974, 0.7692) (0.4515, 0.8586)

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 2, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 150.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 28. | 62. | 59. | 0. | 0. |
| ACTUALLY POSITIVE CASES | 3. | 23. | 78. | 33. | 13. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0000 0.0000 0.3960 0.8121 1.0000
TPF: 0.0000 0.0867 0.3067 0.8267 0.9800 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.2603 B= 0.8325
Z(K)= -0.8855 0.2634 2.6112 2.7112
LOGL= -397.9249
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 7 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.2232 B= 0.6858
Z(K)= -0.9217 0.3090 2.5500 3.7878
LOGL= -345.4767
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0189 | 0.0045 | 0.0052 | 0.0060 | 0.0056 | -0.0005 |
| B | 0.0045 | 0.0099 | 0.0027 | -0.0001 | -0.0269 | -0.0459 |
| Z( 1) | 0.0052 | 0.0027 | 0.0140 | 0.0051 | -0.0023 | -0.0073 |
| Z( 2) | 0.0060 | -0.0001 | 0.0051 | 0.0103 | 0.0087 | 0.0091 |
| Z( 3) | 0.0056 | -0.0269 | -0.0023 | 0.0087 | 0.1115 | 0.1582 |
| Z( 4) | -0.0005 | -0.0459 | -0.0073 | 0.0091 | 0.1582 | 0.2801 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.3270 | 0.3178 | 0.4283 | 0.1216 | -0.0072 |
| B | 0.3270 | 1.0000 | 0.2319 | -0.0120 | -0.8074 | -0.8706 |
| Z( 1) | 0.3178 | 0.2319 | 1.0000 | 0.4245 | -0.0585 | -0.1170 |
| Z( 2) | 0.4283 | -0.0120 | 0.4245 | 1.0000 | 0.2583 | 0.1695 |
| Z( 3) | 0.1216 | -0.8074 | -0.0585 | 0.2583 | 1.0000 | 0.8953 |
| Z( 4) | -0.0072 | -0.8706 | -0.1170 | 0.1695 | 0.8953 | 1.0000 |

AREA = 0.8435 STD. DEV.(AREA) = 0.0258

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.2934 | ( 0.1514 , | 0.4775 ) |
| 0.010 | 0.3548 | ( 0.2065 , | 0.5294 ) |
| 0.020 | 0.4264 | ( 0.2779 , | 0.5864 ) |
| 0.030 | 0.4734 | ( 0.3282 , | 0.6222 ) |
| 0.040 | 0.5089 | ( 0.3680 , | 0.6488 ) |
| 0.050 | 0.5379 | ( 0.4012 , | 0.6702 ) |
| 0.060 | 0.5623 | ( 0.4298 , | 0.6881 ) |
| 0.070 | 0.5836 | ( 0.4550 , | 0.7037 ) |
| 0.080 | 0.6024 | ( 0.4776 , | 0.7174 ) |
| 0.090 | 0.6193 | ( 0.4981 , | 0.7297 ) |
| 0.100 | 0.6347 | ( 0.5169 , | 0.7409 ) |
| 0.110 | 0.6488 | ( 0.5341 , | 0.7512 ) |
| 0.120 | 0.6618 | ( 0.5502 , | 0.7608 ) |
| 0.130 | 0.6739 | ( 0.5651 , | 0.7696 ) |
| 0.140 | 0.6852 | ( 0.5791 , | 0.7779 ) |
| 0.150 | 0.6958 | ( 0.5922 , | 0.7857 ) |
| 0.200 | 0.7409 | ( 0.6482 , | 0.8191 ) |
| 0.250 | 0.7766 | ( 0.6924 , | 0.8460 ) |
| 0.300 | 0.8062 | ( 0.7287 , | 0.8684 ) |
| 0.400 | 0.8531 | ( 0.7859 , | 0.9045 ) |
| 0.500 | 0.8894 | ( 0.8299 , | 0.9322 ) |
| 0.600 | 0.9187 | ( 0.8659 , | 0.9541 ) |
| 0.700 | 0.9432 | ( 0.8970 , | 0.9713 ) |
| 0.800 | 0.9641 | ( 0.9253 , | 0.9846 ) |
| 0.900 | 0.9822 | ( 0.9534 , | 0.9942 ) |
| 0.950 | 0.9906 | ( 0.9692 , | 0.9977 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0001, 0.0847) | (0.0000, 0.0185) | (0.0030, 0.2537) |
| (0.0054, 0.2996) | (0.0007, 0.1650) | (0.0290, 0.4695) |
| (0.3787, 0.8441) | (0.3059, 0.8093) | (0.4560, 0.8744) |
| (0.8217, 0.9682) | (0.7548, 0.9551) | (0.8757, 0.9780) |

# APPENDIX IV

## B II

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 3, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 59.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 100. | 41. | 1. | 6. | 1. |
| ACTUALLY POSITIVE CASES | 6. | 6. | 3. | 10. | 34. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0067 0.0470 0.0537 0.3289 1.0000
TPF: 0.0000 0.5763 0.7458 0.7966 0.8983 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.5514 B= 0.5243
Z(K)= 0.4426 1.6104 1.6752 2.4728
LOGL= -197.8084
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.5534 B= 0.5279
Z(K)= 0.4474 1.5513 1.7104 2.5634
LOGL= -196.4182
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0741 | 0.0289 | 0.0066 | 0.0035 | 0.0017 | -0.0209 |
| B | 0.0289 | 0.0197 | 0.0019 | -0.0042 | -0.0064 | -0.0298 |
| Z( 1) | 0.0066 | 0.0019 | 0.0113 | 0.0065 | 0.0060 | 0.0035 |
| Z( 2) | 0.0035 | -0.0042 | 0.0065 | 0.0246 | 0.0240 | 0.0263 |
| Z( 3) | 0.0017 | -0.0064 | 0.0060 | 0.0240 | 0.0296 | 0.0336 |
| Z( 4) | -0.0209 | -0.0298 | 0.0035 | 0.0263 | 0.0336 | 0.1096 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.7573 | 0.2287 | 0.0831 | 0.0367 | -0.2316 |
| B | 0.7573 | 1.0000 | 0.1262 | -0.1906 | -0.2655 | -0.6429 |
| Z( 1) | 0.2287 | 0.1262 | 1.0000 | 0.3888 | 0.3294 | 0.0989 |
| Z( 2) | 0.0831 | -0.1906 | 0.3888 | 1.0000 | 0.8887 | 0.5059 |
| Z( 3) | 0.0367 | -0.2655 | 0.3294 | 0.8887 | 1.0000 | 0.5900 |
| Z( 4) | -0.2316 | -0.6429 | 0.0989 | 0.5059 | 0.5900 | 1.0000 |

AREA = 0.9152 STD. DEV.(AREA) = 0.0292

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.5767 | ( 0.3939 | , | 0.7440 ) |
| 0.010 | 0.6274 | ( 0.4620 | , | 0.7721 ) |
| 0.020 | 0.6805 | ( 0.5340 | , | 0.8031 ) |
| 0.030 | 0.7124 | ( 0.5769 | , | 0.8229 ) |
| 0.040 | 0.7353 | ( 0.6072 | , | 0.8379 ) |
| 0.050 | 0.7533 | ( 0.6305 | , | 0.8500 ) |
| 0.060 | 0.7681 | ( 0.6492 | , | 0.8603 ) |
| 0.070 | 0.7806 | ( 0.6649 | , | 0.8692 ) |
| 0.080 | 0.7915 | ( 0.6782 | , | 0.8770 ) |
| 0.090 | 0.8011 | ( 0.6898 | , | 0.8841 ) |
| 0.100 | 0.8097 | ( 0.7001 | , | 0.8905 ) |
| 0.110 | 0.8175 | ( 0.7092 | , | 0.8963 ) |
| 0.120 | 0.8246 | ( 0.7175 | , | 0.9016 ) |
| 0.130 | 0.8312 | ( 0.7250 | , | 0.9065 ) |
| 0.140 | 0.8372 | ( 0.7319 | , | 0.9111 ) |
| 0.150 | 0.8429 | ( 0.7383 | , | 0.9153 ) |
| 0.200 | 0.8663 | ( 0.7643 | , | 0.9329 ) |
| 0.250 | 0.8844 | ( 0.7841 | , | 0.9462 ) |
| 0.300 | 0.8992 | ( 0.8001 | , | 0.9565 ) |
| 0.400 | 0.9222 | ( 0.8256 | , | 0.9715 ) |
| 0.500 | 0.9398 | ( 0.8461 | , | 0.9816 ) |
| 0.600 | 0.9542 | ( 0.8641 | , | 0.9885 ) |
| 0.700 | 0.9664 | ( 0.8811 | , | 0.9934 ) |
| 0.800 | 0.9771 | ( 0.8985 | , | 0.9968 ) |
| 0.900 | 0.9871 | ( 0.9188 | , | 0.9989 ) |
| 0.950 | 0.9923 | ( 0.9329 | , | 0.9996 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0052, 0.5793) | (0.0007, 0.4434) | (0.0278, 0.7063) |
| (0.0436, 0.7423) | (0.0203, 0.6817) | (0.0848, 0.7963) |
| (0.0604, 0.7687) | (0.0315, 0.7164) | (0.1068, 0.8151) |
| (0.3273, 0.9061) | (0.2559, 0.8863) | (0.4056, 0.9233) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 3, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 82.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 135. | 10. | 0. | 0. | 4. |
| ACTUALLY POSITIVE CASES | 29. | 1. | 1. | 5. | 46. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0268 0.0268 0.0268 0.0940 1.0000

TPF: 0.0000 0.5610 0.6220 0.6341 0.6463 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.7642 B= 0.2756
Z(K)= 1.3170 1.7297 1.8297 1.9297
LOGL= -142.8031
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.7916 B= 0.3089
Z(K)= 1.3225 1.7410 1.7930 2.0498
LOGL= -140.5911
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0733 | 0.0328 | 0.0093 | -0.0032 | -0.0052 | -0.0172 |
| B | 0.0328 | 0.0204 | 0.0023 | -0.0066 | -0.0080 | -0.0164 |
| Z( 1) | 0.0093 | 0.0023 | 0.0204 | 0.0171 | 0.0168 | 0.0150 |
| Z( 2) | -0.0032 | -0.0066 | 0.0171 | 0.0314 | 0.0315 | 0.0327 |
| Z( 3) | -0.0052 | -0.0080 | 0.0168 | 0.0315 | 0.0340 | 0.0357 |
| Z( 4) | -0.0172 | -0.0164 | 0.0150 | 0.0327 | 0.0357 | 0.0536 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.8490 | 0.2413 | -0.0675 | -0.1051 | -0.2742 |
| B | 0.8490 | 1.0000 | 0.1123 | -0.2591 | -0.3030 | -0.4970 |
| Z( 1) | 0.2413 | 0.1123 | 1.0000 | 0.6764 | 0.6365 | 0.4546 |
| Z( 2) | -0.0675 | -0.2591 | 0.6764 | 1.0000 | 0.9640 | 0.7976 |
| Z( 3) | -0.1051 | -0.3030 | 0.6365 | 0.9640 | 1.0000 | 0.8360 |
| Z( 4) | -0.2742 | -0.4970 | 0.4546 | 0.7976 | 0.8360 | 1.0000 |

AREA = 0.7753 STD. DEV.(AREA) = 0.0699

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.4983 | ( 0.3469 , | 0.6499 ) |
| 0.010 | 0.5290 | ( 0.3929 , | 0.6618 ) |
| 0.020 | 0.5624 | ( 0.4405 , | 0.6785 ) |
| 0.030 | 0.5833 | ( 0.4681 , | 0.6918 ) |
| 0.040 | 0.5989 | ( 0.4870 , | 0.7032 ) |
| 0.050 | 0.6115 | ( 0.5011 , | 0.7136 ) |
| 0.060 | 0.6222 | ( 0.5121 , | 0.7231 ) |
| 0.070 | 0.6314 | ( 0.5210 , | 0.7319 ) |
| 0.080 | 0.6396 | ( 0.5284 , | 0.7401 ) |
| 0.090 | 0.6470 | ( 0.5347 , | 0.7478 ) |
| 0.100 | 0.6538 | ( 0.5400 , | 0.7551 ) |
| 0.110 | 0.6601 | ( 0.5447 , | 0.7620 ) |
| 0.120 | 0.6659 | ( 0.5489 , | 0.7686 ) |
| 0.130 | 0.6713 | ( 0.5526 , | 0.7749 ) |
| 0.140 | 0.6765 | ( 0.5559 , | 0.7808 ) |
| 0.150 | 0.6813 | ( 0.5589 , | 0.7865 ) |
| 0.200 | 0.7025 | ( 0.5707 , | 0.8119 ) |
| 0.250 | 0.7202 | ( 0.5791 , | 0.8332 ) |
| 0.300 | 0.7356 | ( 0.5856 , | 0.8516 ) |

| | | | | | |
|---|---|---|---|---|---|
| 0.400 | 0.7622 | ( | 0.5954 | , 0.8821 | ) |
| 0.500 | 0.7857 | ( | 0.6029 | , 0.9070 | ) |
| 0.600 | 0.8078 | ( | 0.6094 | , 0.9281 | ) |
| 0.700 | 0.8298 | ( | 0.6155 | , 0.9466 | ) |
| 0.800 | 0.8535 | ( | 0.6219 | , 0.9635 | ) |
| 0.900 | 0.8825 | ( | 0.6298 | , 0.9795 | ) |
| 0.950 | 0.9032 | ( | 0.6357 | , 0.9879 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0202, 0.5629) | (0.0062, 0.5073) | (0.0552, 0.6173) |
| (0.0365, 0.5939) | (0.0156, 0.5501) | (0.0761, 0.6366) |
| (0.0408, 0.6001) | (0.0184, 0.5582) | (0.0817, 0.6410) |
| (0.0930, 0.6491) | (0.0545, 0.6165) | (0.1487, 0.6807) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 3, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 27.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 100. | 14. | 0. | 21. | 14. |
| ACTUALLY POSITIVE CASES | 11. | 1. | 0. | 11. | 4. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0940 0.2349 0.3289 1.0000
TPF: 0.0000 0.1481 0.5556 0.5926 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.0544 B= 1.5447
Z(K)= 0.4426 0.7225 1.3170
LOGL= -180.4581
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.9177 B= 1.3982
Z(K)= 0.4487 0.6788 1.3417
LOGL= -179.8747
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:
A 0.1578 0.1213 0.0189 0.0149 -0.0004

| | | | | | |
|---|---|---|---|---|---|
| B | 0.1213 | 0.1589 | 0.0070 | 0.0008 | -0.0213 |
| Z( 1) | 0.0189 | 0.0070 | 0.0113 | 0.0099 | 0.0069 |
| Z( 2) | 0.0149 | 0.0008 | 0.0099 | 0.0119 | 0.0092 |
| Z( 3) | -0.0004 | -0.0213 | 0.0069 | 0.0092 | 0.0207 |

CORRELATION MATRIX:

| | | | | | |
|---|---|---|---|---|---|
| A | 1.0000 | 0.7660 | 0.4469 | 0.3448 | -0.0065 |
| B | 0.7660 | 1.0000 | 0.1651 | 0.0182 | -0.3724 |
| Z( 1) | 0.4469 | 0.1651 | 1.0000 | 0.8521 | 0.4504 |
| Z( 2) | 0.3448 | 0.0182 | 0.8521 | 1.0000 | 0.5831 |
| Z( 3) | -0.0065 | -0.3724 | 0.4504 | 0.5831 | 1.0000 |

AREA = 0.7033 STD. DEV.(AREA) = 0.0578

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.0036 | ( 0.0000 , | 0.1186 ) |
| 0.010 | 0.0098 | ( 0.0001 , | 0.1550 ) |
| 0.020 | 0.0253 | ( 0.0010 , | 0.2037 ) |
| 0.030 | 0.0434 | ( 0.0033 , | 0.2402 ) |
| 0.040 | 0.0629 | ( 0.0071 , | 0.2707 ) |
| 0.050 | 0.0834 | ( 0.0127 , | 0.2978 ) |
| 0.060 | 0.1044 | ( 0.0201 , | 0.3225 ) |
| 0.070 | 0.1259 | ( 0.0290 , | 0.3456 ) |
| 0.080 | 0.1475 | ( 0.0395 , | 0.3675 ) |
| 0.090 | 0.1692 | ( 0.0514 , | 0.3885 ) |
| 0.100 | 0.1909 | ( 0.0645 , | 0.4089 ) |
| 0.110 | 0.2126 | ( 0.0785 , | 0.4287 ) |
| 0.120 | 0.2341 | ( 0.0933 , | 0.4482 ) |
| 0.130 | 0.2555 | ( 0.1088 , | 0.4673 ) |
| 0.140 | 0.2766 | ( 0.1248 , | 0.4863 ) |
| 0.150 | 0.2975 | ( 0.1410 , | 0.5051 ) |
| 0.200 | 0.3979 | ( 0.2227 , | 0.5969 ) |
| 0.250 | 0.4900 | ( 0.2980 , | 0.6845 ) |
| 0.300 | 0.5734 | ( 0.3635 , | 0.7640 ) |
| 0.400 | 0.7136 | ( 0.4698 , | 0.8857 ) |
| 0.500 | 0.8206 | ( 0.5554 , | 0.9551 ) |
| 0.600 | 0.8982 | ( 0.6304 , | 0.9864 ) |
| 0.700 | 0.9506 | ( 0.7009 , | 0.9972 ) |
| 0.800 | 0.9819 | ( 0.7716 , | 0.9997 ) |
| 0.900 | 0.9966 | ( 0.8498 , | 1.0000 ) |
| 0.950 | 0.9994 | ( 0.8981 , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0898, 0.1689) | (0.0522, 0.0881) | (0.1446, 0.2863) |
| (0.2486, 0.4875) | (0.1860, 0.3705) | (0.3210, 0.6056) |
| (0.3268, 0.6142) | (0.2554, 0.4994) | (0.4051, 0.7197) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 3, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 150.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 93. | 42. | 9. | 5. | 0. |
| ACTUALLY POSITIVE CASES | 24. | 42. | 37. | 27. | 20. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0000 0.0336 0.0940 0.3758 1.0000
TPF: 0.0000 0.1333 0.3133 0.5600 0.8400 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.2702 B= 0.8959
Z(K)= 0.3160 1.3170 1.8313 2.7112
LOGL= -378.3870
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.2787 B= 0.8858
Z(K)= 0.3172 1.2914 1.9619 2.7109
LOGL= -376.3607
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0312 | 0.0155 | 0.0106 | 0.0052 | -0.0025 | -0.0137 |
| B | 0.0155 | 0.0171 | 0.0034 | -0.0060 | -0.0167 | -0.0309 |
| Z( 1) | 0.0106 | 0.0034 | 0.0109 | 0.0067 | 0.0044 | 0.0016 |
| Z( 2) | 0.0052 | -0.0060 | 0.0067 | 0.0165 | 0.0189 | 0.0234 |
| Z( 3) | -0.0025 | -0.0167 | 0.0044 | 0.0189 | 0.0361 | 0.0480 |
| Z( 4) | -0.0137 | -0.0309 | 0.0016 | 0.0234 | 0.0480 | 0.0866 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.6727 | 0.5739 | 0.2270 | -0.0744 | -0.2638 |
| B | 0.6727 | 1.0000 | 0.2506 | -0.3583 | -0.6697 | -0.8032 |
| Z( 1) | 0.5739 | 0.2506 | 1.0000 | 0.4988 | 0.2195 | 0.0519 |
| Z( 2) | 0.2270 | -0.3583 | 0.4988 | 1.0000 | 0.7734 | 0.6186 |
| Z( 3) | -0.0744 | -0.6697 | 0.2195 | 0.7734 | 1.0000 | 0.8585 |
| Z( 4) | -0.2638 | -0.8032 | 0.0519 | 0.6186 | 0.8585 | 1.0000 |

AREA = 0.8308 STD. DEV.(AREA) = 0.0256

1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.1578 | ( 0.0665 | , | 0.3070 ) |
| 0.010 | 0.2170 | ( 0.1098 | , | 0.3680 ) |
| 0.020 | 0.2943 | ( 0.1759 | , | 0.4400 ) |
| 0.030 | 0.3491 | ( 0.2280 | , | 0.4880 ) |
| 0.040 | 0.3926 | ( 0.2717 | , | 0.5251 ) |
| 0.050 | 0.4291 | ( 0.3095 | , | 0.5556 ) |
| 0.060 | 0.4606 | ( 0.3431 | , | 0.5818 ) |
| 0.070 | 0.4885 | ( 0.3731 | , | 0.6048 ) |
| 0.080 | 0.5135 | ( 0.4004 | , | 0.6255 ) |
| 0.090 | 0.5362 | ( 0.4253 | , | 0.6443 ) |
| 0.100 | 0.5570 | ( 0.4482 | , | 0.6616 ) |
| 0.110 | 0.5761 | ( 0.4694 | , | 0.6775 ) |
| 0.120 | 0.5940 | ( 0.4891 | , | 0.6924 ) |
| 0.130 | 0.6106 | ( 0.5075 | , | 0.7064 ) |
| 0.140 | 0.6261 | ( 0.5247 | , | 0.7195 ) |
| 0.150 | 0.6408 | ( 0.5408 | , | 0.7319 ) |
| 0.200 | 0.7031 | ( 0.6090 | , | 0.7852 ) |
| 0.250 | 0.7522 | ( 0.6622 | , | 0.8275 ) |
| 0.300 | 0.7923 | ( 0.7055 | , | 0.8619 ) |
| 0.400 | 0.8542 | ( 0.7729 | , | 0.9132 ) |
| 0.500 | 0.8995 | ( 0.8245 | , | 0.9479 ) |
| 0.600 | 0.9335 | ( 0.8665 | , | 0.9710 ) |
| 0.700 | 0.9593 | ( 0.9024 | , | 0.9858 ) |
| 0.800 | 0.9785 | ( 0.9342 | , | 0.9945 ) |
| 0.900 | 0.9921 | ( 0.9638 | , | 0.9988 ) |
| 0.950 | 0.9969 | ( 0.9790 | , | 0.9997 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0034, 0.1308) | (0.0005, 0.0512) | (0.0164, 0.2704) |
| (0.0249, 0.3230) | (0.0098, 0.2150) | (0.0560, 0.4486) |
| (0.0983, 0.5536) | (0.0613, 0.4647) | (0.1493, 0.6398) |
| (0.3755, 0.8408) | (0.3010, 0.7929) | (0.4551, 0.8807) |

# APPENDIX IV

# B III

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 4, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 59.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 38. | 61. | 40. | 8. | 2. |
| ACTUALLY POSITIVE CASES | 2. | 3. | 16. | 6. | 32. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0134 0.0671 0.3356 0.7450 1.0000
TPF: 0.0000 0.5424 0.6441 0.9153 0.9661 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.4749 B= 0.6394
Z(K)= -0.6584 0.4241 1.4979 2.2142
LOGL= -263.4115
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.4939 B= 0.6633
Z(K)= -0.6526 0.4028 1.5744 2.1027
LOGL= -262.5013
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0536 | 0.0202 | 0.0051 | 0.0058 | 0.0046 | -0.0010 |
| B | 0.0202 | 0.0175 | 0.0020 | 0.0010 | -0.0061 | -0.0151 |
| Z( 1) | 0.0051 | 0.0020 | 0.0122 | 0.0052 | 0.0026 | 0.0015 |
| Z( 2) | 0.0058 | 0.0010 | 0.0052 | 0.0108 | 0.0064 | 0.0055 |
| Z( 3) | 0.0046 | -0.0061 | 0.0026 | 0.0064 | 0.0251 | 0.0257 |
| Z( 4) | -0.0010 | -0.0151 | 0.0015 | 0.0055 | 0.0257 | 0.0492 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.6613 | 0.1977 | 0.2416 | 0.1252 | -0.0192 |
| B | 0.6613 | 1.0000 | 0.1374 | 0.0691 | -0.2914 | -0.5166 |
| Z( 1) | 0.1977 | 0.1374 | 1.0000 | 0.4489 | 0.1491 | 0.0602 |
| Z( 2) | 0.2416 | 0.0691 | 0.4489 | 1.0000 | 0.3873 | 0.2376 |
| Z( 3) | 0.1252 | -0.2914 | 0.1491 | 0.3873 | 1.0000 | 0.7321 |
| Z( 4) | -0.0192 | -0.5166 | 0.0602 | 0.2376 | 0.7321 | 1.0000 |

AREA = 0.8934 STD. DEV.(AREA) = 0.0282

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.4149 | ( 0.2371 | , | 0.6125 ) |
| 0.010 | 0.4803 | ( 0.3068 | , | 0.6577 ) |
| 0.020 | 0.5523 | ( 0.3895 | , | 0.7066 ) |
| 0.030 | 0.5972 | ( 0.4434 | , | 0.7371 ) |
| 0.040 | 0.6302 | ( 0.4837 | , | 0.7598 ) |
| 0.050 | 0.6564 | ( 0.5159 | , | 0.7780 ) |
| 0.060 | 0.6781 | ( 0.5426 | , | 0.7933 ) |
| 0.070 | 0.6967 | ( 0.5654 | , | 0.8065 ) |
| 0.080 | 0.7129 | ( 0.5853 | , | 0.8181 ) |
| 0.090 | 0.7272 | ( 0.6029 | , | 0.8284 ) |
| 0.100 | 0.7401 | ( 0.6187 | , | 0.8378 ) |
| 0.110 | 0.7518 | ( 0.6329 | , | 0.8464 ) |
| 0.120 | 0.7625 | ( 0.6459 | , | 0.8542 ) |
| 0.130 | 0.7724 | ( 0.6578 | , | 0.8615 ) |
| 0.140 | 0.7815 | ( 0.6688 | , | 0.8683 ) |
| 0.150 | 0.7900 | ( 0.6789 | , | 0.8746 ) |
| 0.200 | 0.8253 | ( 0.7210 | , | 0.9007 ) |
| 0.250 | 0.8524 | ( 0.7531 | , | 0.9206 ) |
| 0.300 | 0.8742 | ( 0.7789 | , | 0.9363 ) |
| 0.400 | 0.9076 | ( 0.8194 | , | 0.9590 ) |
| 0.500 | 0.9324 | ( 0.8509 | , | 0.9743 ) |
| 0.600 | 0.9517 | ( 0.8774 | , | 0.9847 ) |
| 0.700 | 0.9672 | ( 0.9012 | , | 0.9917 ) |
| 0.800 | 0.9799 | ( 0.9240 | , | 0.9962 ) |
| 0.900 | 0.9905 | ( 0.9480 | , | 0.9989 ) |
| 0.950 | 0.9951 | ( 0.9627 | , | 0.9996 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0177, 0.5395) | (0.0056, 0.4250) | (0.0477, 0.6509) |
| (0.0577, 0.6735) | (0.0297, 0.5962) | (0.1032, 0.7440) |
| (0.3436, 0.8900) | (0.2720, 0.8624) | (0.4213, 0.9134) |
| (0.7430, 0.9730) | (0.6685, 0.9627) | (0.8077, 0.9808) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 4, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 82.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 34. | 89. | 21. | 2. | 3. |
| ACTUALLY POSITIVE CASES | 3. | 27. | 12. | 7. | 33. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0201 0.0336 0.1745 0.7718 1.0000

TPF: 0.0000 0.4024 0.4878 0.6341 0.9634 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.1938 B= 0.7160
Z(K)= -0.7446 0.9365 1.8313 2.0514
LOGL= -270.8926
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.1283 B= 0.7053
Z(K)= -0.7614 0.9868 1.6973 1.9788
LOGL= -269.4543
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0311 | 0.0109 | 0.0060 | 0.0065 | 0.0040 | 0.0022 |
| B | 0.0109 | 0.0120 | 0.0028 | -0.0015 | -0.0078 | -0.0114 |
| Z( 1) | 0.0060 | 0.0028 | 0.0129 | 0.0037 | 0.0019 | 0.0011 |
| Z( 2) | 0.0065 | -0.0015 | 0.0037 | 0.0140 | 0.0125 | 0.0125 |
| Z( 3) | 0.0040 | -0.0078 | 0.0019 | 0.0125 | 0.0273 | 0.0283 |
| Z( 4) | 0.0022 | -0.0114 | 0.0011 | 0.0125 | 0.0283 | 0.0381 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.5610 | 0.3014 | 0.3090 | 0.1366 | 0.0635 |
| B | 0.5610 | 1.0000 | 0.2234 | -0.1165 | -0.4327 | -0.5335 |
| Z( 1) | 0.3014 | 0.2234 | 1.0000 | 0.2754 | 0.1009 | 0.0480 |
| Z( 2) | 0.3090 | -0.1165 | 0.2754 | 1.0000 | 0.6388 | 0.5420 |
| Z( 3) | 0.1366 | -0.4327 | 0.1009 | 0.6388 | 1.0000 | 0.8771 |
| Z( 4) | 0.0635 | -0.5335 | 0.0480 | 0.5420 | 0.8771 | 1.0000 |

AREA = 0.8217 STD. DEV.(AREA) = 0.0323

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.2455 | ( 0.1253 , | 0.4095 ) |
| 0.010 | 0.3040 | ( 0.1756 , | 0.4627 ) |
| 0.020 | 0.3743 | ( 0.2422 , | 0.5231 ) |
| 0.030 | 0.4213 | ( 0.2898 , | 0.5623 ) |
| 0.040 | 0.4575 | ( 0.3277 , | 0.5920 ) |
| 0.050 | 0.4872 | ( 0.3595 , | 0.6162 ) |
| 0.060 | 0.5125 | ( 0.3869 , | 0.6369 ) |
| 0.070 | 0.5347 | ( 0.4112 , | 0.6550 ) |
| 0.080 | 0.5545 | ( 0.4330 , | 0.6711 ) |
| 0.090 | 0.5724 | ( 0.4527 , | 0.6857 ) |
| 0.100 | 0.5887 | ( 0.4708 , | 0.6991 ) |
| 0.110 | 0.6037 | ( 0.4875 , | 0.7114 ) |
| 0.120 | 0.6177 | ( 0.5030 , | 0.7229 ) |
| 0.130 | 0.6307 | ( 0.5174 , | 0.7336 ) |
| 0.140 | 0.6429 | ( 0.5310 , | 0.7437 ) |
| 0.150 | 0.6544 | ( 0.5437 , | 0.7532 ) |
| 0.200 | 0.7036 | ( 0.5981 , | 0.7942 ) |
| 0.250 | 0.7430 | ( 0.6415 , | 0.8271 ) |
| 0.300 | 0.7760 | ( 0.6777 , | 0.8545 ) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.400 | 0.8289 | ( | 0.7362 | , | 0.8976 | ) |
| 0.500 | 0.8704 | ( | 0.7831 | , | 0.9297 | ) |
| 0.600 | 0.9043 | ( | 0.8233 | , | 0.9540 | ) |
| 0.700 | 0.9329 | ( | 0.8596 | , | 0.9724 | ) |
| 0.800 | 0.9574 | ( | 0.8944 | , | 0.9859 | ) |
| 0.900 | 0.9789 | ( | 0.9309 | , | 0.9951 | ) |
| 0.950 | 0.9890 | ( | 0.9526 | , | 0.9982 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0239, 0.3946) | (0.0091, 0.2956) | (0.0552, 0.5009) |
| (0.0448, 0.4725) | (0.0216, 0.3831) | (0.0848, 0.5633) |
| (0.1619, 0.6672) | (0.1114, 0.6059) | (0.2252, 0.7244) |
| (0.7768, 0.9521) | (0.7049, 0.9342) | (0.8375, 0.9658) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 4, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 27.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 22. | 58. | 19. | 26. | 24. |
| ACTUALLY POSITIVE CASES | 3. | 6. | 3. | 0. | 15. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.1611 0.3356 0.4631 0.8523 1.0000
TPF: 0.0000 0.5556 0.5556 0.6667 0.8889 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.5715 B= 0.5571
Z(K)= -1.0466 0.0924 0.4241 0.9900
LOGL= -260.0469
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.5870 B= 0.5037
Z(K)= -1.0604 0.1050 0.4573 0.9660
LOGL= -259.7316
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0526 | 0.0065 | 0.0041 | 0.0035 | 0.0036 | 0.0040 |

| | | | | | | |
|---|---|---|---|---|---|---|
| B | 0.0065 | 0.0229 | 0.0031 | 0.0000 | -0.0010 | -0.0032 |
| Z( 1) | 0.0041 | 0.0031 | 0.0159 | 0.0051 | 0.0039 | 0.0027 |
| Z( 2) | 0.0035 | 0.0000 | 0.0051 | 0.0104 | 0.0082 | 0.0063 |
| Z( 3) | 0.0036 | -0.0010 | 0.0039 | 0.0082 | 0.0111 | 0.0086 |
| Z( 4) | 0.0040 | -0.0032 | 0.0027 | 0.0063 | 0.0086 | 0.0148 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.1880 | 0.1413 | 0.1485 | 0.1479 | 0.1443 |
| B | 0.1880 | 1.0000 | 0.1599 | 0.0013 | -0.0638 | -0.1762 |
| Z( 1) | 0.1413 | 0.1599 | 1.0000 | 0.3950 | 0.2940 | 0.1776 |
| Z( 2) | 0.1485 | 0.0013 | 0.3950 | 1.0000 | 0.7640 | 0.5067 |
| Z( 3) | 0.1479 | -0.0638 | 0.2940 | 0.7640 | 1.0000 | 0.6694 |
| Z( 4) | 0.1443 | -0.1762 | 0.1776 | 0.5067 | 0.6694 | 1.0000 |

AREA = 0.6999 STD. DEV.(AREA) = 0.0700

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.2386 | ( 0.0642 , | 0.5396 ) |
| 0.010 | 0.2793 | ( 0.0911 , | 0.5652 ) |
| 0.020 | 0.3272 | ( 0.1285 , | 0.5940 ) |
| 0.030 | 0.3592 | ( 0.1568 , | 0.6128 ) |
| 0.040 | 0.3840 | ( 0.1802 , | 0.6272 ) |
| 0.050 | 0.4045 | ( 0.2006 , | 0.6391 ) |
| 0.060 | 0.4222 | ( 0.2187 , | 0.6495 ) |
| 0.070 | 0.4378 | ( 0.2352 , | 0.6586 ) |
| 0.080 | 0.4519 | ( 0.2504 , | 0.6670 ) |
| 0.090 | 0.4647 | ( 0.2645 , | 0.6746 ) |
| 0.100 | 0.4766 | ( 0.2776 , | 0.6817 ) |
| 0.110 | 0.4877 | ( 0.2901 , | 0.6884 ) |
| 0.120 | 0.4980 | ( 0.3018 , | 0.6947 ) |
| 0.130 | 0.5078 | ( 0.3130 , | 0.7008 ) |
| 0.140 | 0.5171 | ( 0.3236 , | 0.7065 ) |
| 0.150 | 0.5259 | ( 0.3338 , | 0.7120 ) |
| 0.200 | 0.5648 | ( 0.3790 , | 0.7371 ) |
| 0.250 | 0.5977 | ( 0.4173 , | 0.7592 ) |
| 0.300 | 0.6267 | ( 0.4506 , | 0.7794 ) |
| 0.400 | 0.6771 | ( 0.5072 , | 0.8162 ) |
| 0.500 | 0.7214 | ( 0.5547 , | 0.8500 ) |
| 0.600 | 0.7625 | ( 0.5968 , | 0.8817 ) |
| 0.700 | 0.8026 | ( 0.6363 , | 0.9120 ) |
| 0.800 | 0.8439 | ( 0.6763 , | 0.9411 ) |
| 0.900 | 0.8911 | ( 0.7230 , | 0.9695 ) |
| 0.950 | 0.9216 | ( 0.7558 , | 0.9838 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.1670, 0.5400) | (0.1143, 0.4922) | (0.2333, 0.5872) |

(0.3237, 0.6393) (0.2533, 0.5996) (0.4011, 0.6775)
(0.4582, 0.7034) (0.3804, 0.6677) (0.5377, 0.7371)
(0.8555, 0.8689) (0.7919, 0.8405) (0.9045, 0.8936)

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 4, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 150.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 27. | 90. | 32. | 0. | 0. |
| ACTUALLY POSITIVE CASES | 7. | 45. | 61. | 25. | 12. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0000 0.0000 0.2148 0.8188 1.0000
TPF: 0.0000 0.0800 0.2467 0.6533 0.9533 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.9927 B= 0.7668
Z(K)= -0.9107 0.7898 2.6112 2.7112
LOGL= -384.2195
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 7 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.9878 B= 0.6626
Z(K)= -0.9335 0.8314 2.5567 3.6335
LOGL= -347.6042
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0162 | 0.0042 | 0.0057 | 0.0058 | 0.0026 | -0.0026 |
| B | 0.0042 | 0.0074 | 0.0031 | -0.0018 | -0.0188 | -0.0317 |
| Z( 1) | 0.0057 | 0.0031 | 0.0143 | 0.0038 | -0.0029 | -0.0079 |
| Z( 2) | 0.0058 | -0.0018 | 0.0038 | 0.0126 | 0.0148 | 0.0178 |
| Z( 3) | 0.0026 | -0.0188 | -0.0029 | 0.0148 | 0.0832 | 0.1112 |
| Z( 4) | -0.0026 | -0.0317 | -0.0079 | 0.0178 | 0.1112 | 0.2013 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.3869 | 0.3724 | 0.4085 | 0.0700 | -0.0449 |
| B | 0.3869 | 1.0000 | 0.2980 | -0.1812 | -0.7584 | -0.8210 |
| Z( 1) | 0.3724 | 0.2980 | 1.0000 | 0.2866 | -0.0835 | -0.1477 |
| Z( 2) | 0.4085 | -0.1812 | 0.2866 | 1.0000 | 0.4581 | 0.3540 |
| Z( 3) | 0.0700 | -0.7584 | -0.0835 | 0.4581 | 1.0000 | 0.8593 |
| Z( 4) | -0.0449 | -0.8210 | -0.1477 | 0.3540 | 0.8593 | 1.0000 |

AREA = 0.7949 STD. DEV.(AREA) = 0.0279

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.2360 | ( 0.1295 , | 0.3783 ) |
| 0.010 | 0.2898 | ( 0.1764 , | 0.4291 ) |
| 0.020 | 0.3545 | ( 0.2378 , | 0.4868 ) |
| 0.030 | 0.3979 | ( 0.2817 , | 0.5241 ) |
| 0.040 | 0.4315 | ( 0.3167 , | 0.5525 ) |
| 0.050 | 0.4593 | ( 0.3463 , | 0.5756 ) |
| 0.060 | 0.4830 | ( 0.3720 , | 0.5953 ) |
| 0.070 | 0.5039 | ( 0.3949 , | 0.6126 ) |
| 0.080 | 0.5226 | ( 0.4156 , | 0.6280 ) |
| 0.090 | 0.5395 | ( 0.4344 , | 0.6419 ) |
| 0.100 | 0.5551 | ( 0.4518 , | 0.6547 ) |
| 0.110 | 0.5695 | ( 0.4680 , | 0.6666 ) |
| 0.120 | 0.5829 | ( 0.4830 , | 0.6776 ) |
| 0.130 | 0.5954 | ( 0.4971 , | 0.6879 ) |
| 0.140 | 0.6072 | ( 0.5105 , | 0.6977 ) |
| 0.150 | 0.6183 | ( 0.5230 , | 0.7069 ) |
| 0.200 | 0.6665 | ( 0.5775 , | 0.7470 ) |
| 0.250 | 0.7058 | ( 0.6218 , | 0.7800 ) |
| 0.300 | 0.7391 | ( 0.6592 , | 0.8082 ) |
| 0.400 | 0.7940 | ( 0.7203 , | 0.8547 ) |
| 0.500 | 0.8384 | ( 0.7698 , | 0.8921 ) |
| 0.600 | 0.8760 | ( 0.8123 , | 0.9229 ) |
| 0.700 | 0.9091 | ( 0.8507 , | 0.9485 ) |
| 0.800 | 0.9389 | ( 0.8876 , | 0.9698 ) |
| 0.900 | 0.9669 | ( 0.9263 , | 0.9870 ) |
| 0.950 | 0.9811 | ( 0.9493 , | 0.9941 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0001, 0.0778) | (0.0000, 0.0226) | (0.0029, 0.2013) |
| (0.0053, 0.2400) | (0.0009, 0.1399) | (0.0232, 0.3701) |
| (0.2029, 0.6689) | (0.1466, 0.6146) | (0.2704, 0.7199) |
| (0.8247, 0.9459) | (0.7579, 0.9267) | (0.8785, 0.9609) |

# APPENDIX IV

## B IV

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 5, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 59.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 104. | 33. | 7. | 3. | 2. |
| ACTUALLY POSITIVE CASES | 5. | 10. | 2. | 13. | 29. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0134 0.0336 0.0805 0.3020 1.0000
TPF: 0.0000 0.4915 0.7119 0.7458 0.9153 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.7869 B= 0.7670
Z(K)= 0.5182 1.4017 1.8313 2.2142
LOGL= -210.7154
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.7799 B= 0.7652
Z(K)= 0.5196 1.4144 1.6996 2.3413
LOGL= -207.9325
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0959 | 0.0452 | 0.0101 | 0.0059 | 0.0006 | -0.0215 |
| B | 0.0452 | 0.0331 | 0.0029 | -0.0047 | -0.0105 | -0.0319 |
| Z( 1) | 0.0101 | 0.0029 | 0.0116 | 0.0074 | 0.0065 | 0.0043 |
| Z( 2) | 0.0059 | -0.0047 | 0.0074 | 0.0205 | 0.0198 | 0.0212 |
| Z( 3) | 0.0006 | -0.0105 | 0.0065 | 0.0198 | 0.0282 | 0.0323 |
| Z( 4) | -0.0215 | -0.0319 | 0.0043 | 0.0212 | 0.0323 | 0.0723 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.8029 | 0.3034 | 0.1335 | 0.0116 | -0.2584 |
| B | 0.8029 | 1.0000 | 0.1497 | -0.1790 | -0.3442 | -0.6523 |
| Z( 1) | 0.3034 | 0.1497 | 1.0000 | 0.4809 | 0.3579 | 0.1499 |
| Z( 2) | 0.1335 | -0.1790 | 0.4809 | 1.0000 | 0.8239 | 0.5521 |
| Z( 3) | 0.0116 | -0.3442 | 0.3579 | 0.8239 | 1.0000 | 0.7148 |
| Z( 4) | -0.2584 | -0.6523 | 0.1499 | 0.5521 | 0.7148 | 1.0000 |

AREA = 0.9213 STD. DEV.(AREA) = 0.0241

1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.4241 | ( 0.2255 , | 0.6448 ) |
| 0.010 | 0.4998 | ( 0.3092 , | 0.6905 ) |
| 0.020 | 0.5824 | ( 0.4096 , | 0.7405 ) |
| 0.030 | 0.6333 | ( 0.4741 , | 0.7722 ) |
| 0.040 | 0.6701 | ( 0.5212 , | 0.7958 ) |
| 0.050 | 0.6988 | ( 0.5580 , | 0.8149 ) |
| 0.060 | 0.7224 | ( 0.5879 , | 0.8310 ) |
| 0.070 | 0.7423 | ( 0.6128 , | 0.8448 ) |
| 0.080 | 0.7595 | ( 0.6340 , | 0.8570 ) |
| 0.090 | 0.7745 | ( 0.6524 , | 0.8678 ) |
| 0.100 | 0.7879 | ( 0.6686 , | 0.8775 ) |
| 0.110 | 0.7999 | ( 0.6829 , | 0.8862 ) |
| 0.120 | 0.8108 | ( 0.6958 , | 0.8942 ) |
| 0.130 | 0.8207 | ( 0.7075 , | 0.9015 ) |
| 0.140 | 0.8298 | ( 0.7181 , | 0.9081 ) |
| 0.150 | 0.8381 | ( 0.7278 , | 0.9143 ) |
| 0.200 | 0.8720 | ( 0.7668 , | 0.9387 ) |
| 0.250 | 0.8969 | ( 0.7955 , | 0.9557 ) |
| 0.300 | 0.9160 | ( 0.8182 , | 0.9678 ) |
| 0.400 | 0.9437 | ( 0.8529 , | 0.9832 ) |
| 0.500 | 0.9625 | ( 0.8796 , | 0.9915 ) |
| 0.600 | 0.9758 | ( 0.9018 , | 0.9960 ) |
| 0.700 | 0.9854 | ( 0.9216 , | 0.9984 ) |
| 0.800 | 0.9923 | ( 0.9403 , | 0.9995 ) |
| 0.900 | 0.9971 | ( 0.9599 , | 0.9999 ) |
| 0.950 | 0.9988 | ( 0.9717 , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0096, 0.4954) | (0.0021, 0.3391) | (0.0348, 0.6524) |
| (0.0446, 0.6842) | (0.0213, 0.5901) | (0.0852, 0.7676) |
| (0.0786, 0.7573) | (0.0450, 0.6855) | (0.1284, 0.8192) |
| (0.3017, 0.9166) | (0.2324, 0.8889) | (0.3789, 0.9387) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 5, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 82.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 116. | 19. | 3. | 3. | 8. |
| ACTUALLY POSITIVE CASES | 3. | 27. | 12. | 7. | 33. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0537 0.0738 0.0940 0.2215 1.0000

```
 TPF: 0.0000 0.4024 0.4878 0.6341 0.9634 1.0000

       INITIAL VALUES OF PARAMETERS:
A=  3.6757    B=  2.4979
Z(K)=  0.7670    1.3170    1.4482    1.6104
LOGL=  -227.2513
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER   4 ITERATIONS.

       FINAL VALUES OF PARAMETERS:
A=  3.6478    B=  2.4614
Z(K)=  0.7655    1.3378    1.4848    1.5864
LOGL=  -225.6613
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

       VARIANCE-COVARIANCE MATRIX:
A       0.4865  0.3474  0.0421  0.0053 -0.0113 -0.0232
B       0.3474  0.3153  0.0132 -0.0285 -0.0443 -0.0555
Z( 1)   0.0421  0.0132  0.0131  0.0099  0.0091  0.0086
Z( 2)   0.0053 -0.0285  0.0099  0.0184  0.0194  0.0203
Z( 3) -0.0113 -0.0443  0.0091  0.0194  0.0226  0.0239
Z( 4) -0.0232 -0.0555  0.0086  0.0203  0.0239  0.0265

       CORRELATION MATRIX:
A       1.0000  0.8870  0.5283  0.0564 -0.1078 -0.2046
B       0.8870  1.0000  0.2060 -0.3742 -0.5251 -0.6069
Z( 1)   0.5283  0.2060  1.0000  0.6380  0.5312  0.4623
Z( 2)   0.0564 -0.3742  0.6380  1.0000  0.9540  0.9176
Z( 3) -0.1078 -0.5251  0.5312  0.9540  1.0000  0.9757
Z( 4) -0.2046 -0.6069  0.4623  0.9176  0.9757  1.0000

     AREA =  0.9151        STD. DEV.(AREA) =  0.0197
1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

   FPF       TPF        (LOWER BOUND, UPPER BOUND)

 0.005     0.0035      (   0.0000  ,   0.1705   )
 0.010     0.0188      (   0.0002  ,   0.2774   )
 0.020     0.0795      (   0.0042  ,   0.4267   )
 0.030     0.1629      (   0.0203  ,   0.5328   )
 0.040     0.2539      (   0.0531  ,   0.6145   )
 0.050     0.3439      (   0.1018  ,   0.6801   )
 0.060     0.4286      (   0.1624  ,   0.7339   )
 0.070     0.5058      (   0.2299  ,   0.7789   )
 0.080     0.5748      (   0.2996  ,   0.8167   )
 0.090     0.6357      (   0.3681  ,   0.8487   )
 0.100     0.6890      (   0.4330  ,   0.8759   )
 0.110     0.7351      (   0.4930  ,   0.8988   )
 0.120     0.7750      (   0.5474  ,   0.9180   )
 0.130     0.8092      (   0.5961  ,   0.9341   )
 0.140     0.8386      (   0.6394  ,   0.9474   )
 0.150     0.8636      (   0.6777  ,   0.9584   )
 0.200     0.9426      (   0.8115  ,   0.9884   )
 0.250     0.9766      (   0.8851  ,   0.9972   )
 0.300     0.9908      (   0.9281  ,   0.9994   )
```

| | | | | | |
|---|---|---|---|---|---|
| 0.400 | 0.9988 | ( | 0.9711 , | 1.0000 | ) |
| 0.500 | 0.9999 | ( | 0.9887 , | 1.0000 | ) |
| 0.600 | 1.0000 | ( | 0.9960 , | 1.0000 | ) |
| 0.700 | 1.0000 | ( | 0.9988 , | 1.0000 | ) |
| 0.800 | 1.0000 | ( | 0.9998 , | 1.0000 | ) |
| 0.900 | 1.0000 | ( | 1.0000 , | 1.0000 | ) |
| 0.950 | 1.0000 | ( | 1.0000 , | 1.0000 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0563, 0.3986) | (0.0283, 0.1485) | (0.1026, 0.7016) |
| (0.0688, 0.4972) | (0.0376, 0.2320) | (0.1170, 0.7636) |
| (0.0905, 0.6387) | (0.0544, 0.3825) | (0.1418, 0.8434) |
| (0.2220, 0.9611) | (0.1612, 0.8872) | (0.2941, 0.9897) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 5, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 27.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 111. | 26. | 4. | 6. | 2. |
| ACTUALLY POSITIVE CASES | 13. | 4. | 2. | 3. | 5. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0134 0.0537 0.0805 0.2550 1.0000
TPF: 0.0000 0.1852 0.2963 0.3704 0.5185 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.4690 B= 0.6101
Z(K)= 0.6584 1.4017 1.6104 2.2142
LOGL= -158.0757
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 3 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.4488 B= 0.5997
Z(K)= 0.6599 1.3843 1.6234 2.2257
LOGL= -158.0101
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:
A 0.1054 0.0456 0.0090 0.0031 0.0000 -0.0132

| | | | | | | |
|---|---|---|---|---|---|---|
| B | 0.0456 | 0.0390 | 0.0026 | -0.0041 | -0.0076 | -0.0227 |
| Z( 1) | 0.0090 | 0.0026 | 0.0124 | 0.0086 | 0.0077 | 0.0058 |
| Z( 2) | 0.0031 | -0.0041 | 0.0086 | 0.0206 | 0.0193 | 0.0181 |
| Z( 3) | 0.0000 | -0.0076 | 0.0077 | 0.0193 | 0.0273 | 0.0261 |
| Z( 4) | -0.0132 | -0.0227 | 0.0058 | 0.0181 | 0.0261 | 0.0689 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.7112 | 0.2506 | 0.0663 | 0.0009 | -0.1547 |
| B | 0.7112 | 1.0000 | 0.1173 | -0.1452 | -0.2333 | -0.4373 |
| Z( 1) | 0.2506 | 0.1173 | 1.0000 | 0.5374 | 0.4195 | 0.1978 |
| Z( 2) | 0.0663 | -0.1452 | 0.5374 | 1.0000 | 0.8143 | 0.4807 |
| Z( 3) | 0.0009 | -0.2333 | 0.4195 | 0.8143 | 1.0000 | 0.6019 |
| Z( 4) | -0.1547 | -0.4373 | 0.1978 | 0.4807 | 0.6019 | 1.0000 |

AREA = 0.6499 STD. DEV.(AREA) = 0.0947

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1365 | ( 0.0359 , | 0.3478 ) |
| 0.010 | 0.1720 | ( 0.0571 , | 0.3770 ) |
| 0.020 | 0.2168 | ( 0.0891 , | 0.4131 ) |
| 0.030 | 0.2485 | ( 0.1141 , | 0.4389 ) |
| 0.040 | 0.2738 | ( 0.1352 , | 0.4600 ) |
| 0.050 | 0.2954 | ( 0.1535 , | 0.4785 ) |
| 0.060 | 0.3143 | ( 0.1697 , | 0.4952 ) |
| 0.070 | 0.3313 | ( 0.1843 , | 0.5106 ) |
| 0.080 | 0.3468 | ( 0.1975 , | 0.5250 ) |
| 0.090 | 0.3612 | ( 0.2097 , | 0.5386 ) |
| 0.100 | 0.3746 | ( 0.2209 , | 0.5516 ) |
| 0.110 | 0.3871 | ( 0.2313 , | 0.5640 ) |
| 0.120 | 0.3990 | ( 0.2410 , | 0.5759 ) |
| 0.130 | 0.4103 | ( 0.2501 , | 0.5874 ) |
| 0.140 | 0.4211 | ( 0.2586 , | 0.5986 ) |
| 0.150 | 0.4314 | ( 0.2667 , | 0.6093 ) |
| 0.200 | 0.4778 | ( 0.3013 , | 0.6588 ) |
| 0.250 | 0.5178 | ( 0.3292 , | 0.7023 ) |
| 0.300 | 0.5535 | ( 0.3528 , | 0.7411 ) |
| 0.400 | 0.6168 | ( 0.3922 , | 0.8073 ) |
| 0.500 | 0.6732 | ( 0.4256 , | 0.8611 ) |
| 0.600 | 0.7259 | ( 0.4567 , | 0.9049 ) |
| 0.700 | 0.7773 | ( 0.4879 , | 0.9402 ) |
| 0.800 | 0.8298 | ( 0.5222 , | 0.9679 ) |
| 0.900 | 0.8883 | ( 0.5669 , | 0.9883 ) |
| 0.950 | 0.9244 | ( 0.6017 , | 0.9955 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0130, 0.1878) | (0.0031, 0.1162) | (0.0435, 0.2818) |

```
(0.0523, 0.2999)          (0.0258, 0.2362)     (0.0968, 0.3705)
(0.0831, 0.3515)          (0.0479, 0.2911)     (0.1351, 0.4159)
(0.2547, 0.5212)          (0.1900, 0.4691)     (0.3292, 0.5729)
1                      R O C F I T (JUNE 1993 VERSION) :

 M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
           F R O M   R A T I N G   D A T A


  DATA DESCRIPTION: Reader 5, Benign or Malignant

  DATA COLLECTED IN  5 CATEGORIES
  WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

  NO. OF ACTUALLY NEGATIVE CASES =  149.     NO. OF ACTUALLY POSITIVE CASES =  150.

  RESPONSE DATA:
   CATEGORY                    1      2      3      4      5
   ACTUALLY NEGATIVE CASES    83.    47.    14.     5.     0.
   ACTUALLY POSITIVE CASES    12.    51.    17.    44.    26.

  OBSERVED OPERATING POINTS:
   FPF: 0.0000 0.0000 0.0336 0.1275 0.4430 1.0000
   TPF: 0.0000 0.1733 0.4667 0.5800 0.9200 1.0000

         INITIAL VALUES OF PARAMETERS:
  A=  1.4291    B=  0.8815
  Z(K)=  0.1432    1.1383    1.8313    2.7112
  LOGL=  -384.7947
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

  PROCEDURE CONVERGES AFTER   4 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
  A=  1.4421    B=  0.9120
  Z(K)=  0.1247    1.2686    1.6829    2.6384
  LOGL=  -378.6452
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

         VARIANCE-COVARIANCE MATRIX:
  A       0.0313  0.0148  0.0098  0.0061  0.0023 -0.0103
  B       0.0148  0.0167  0.0034 -0.0058 -0.0116 -0.0288
  Z( 1)   0.0098  0.0034  0.0105  0.0058  0.0044  0.0010
  Z( 2)   0.0061 -0.0058  0.0058  0.0165  0.0175  0.0226
  Z( 3)   0.0023 -0.0116  0.0044  0.0175  0.0255  0.0356
  Z( 4)  -0.0103 -0.0288  0.0010  0.0226  0.0356  0.0777

         CORRELATION MATRIX:
  A       1.0000  0.6487  0.5393  0.2689  0.0797 -0.2097
  B       0.6487  1.0000  0.2560 -0.3462 -0.5634 -0.7976
  Z( 1)   0.5393  0.2560  1.0000  0.4366  0.2684  0.0361
  Z( 2)   0.2689 -0.3462  0.4366  1.0000  0.8534  0.6315
  Z( 3)   0.0797 -0.5634  0.2684  0.8534  1.0000  0.7996
  Z( 4)  -0.2097 -0.7976  0.0361  0.6315  0.7996  1.0000

       AREA =  0.8567        STD. DEV.(AREA) =  0.0228
1
  ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
  BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
  TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1821 | ( 0.0792 , | 0.3429 ) |
| 0.010 | 0.2483 | ( 0.1292 , | 0.4092 ) |
| 0.020 | 0.3331 | ( 0.2039 , | 0.4861 ) |
| 0.030 | 0.3922 | ( 0.2616 , | 0.5364 ) |
| 0.040 | 0.4384 | ( 0.3093 , | 0.5746 ) |
| 0.050 | 0.4767 | ( 0.3502 , | 0.6057 ) |
| 0.060 | 0.5095 | ( 0.3860 , | 0.6321 ) |
| 0.070 | 0.5382 | ( 0.4179 , | 0.6551 ) |
| 0.080 | 0.5637 | ( 0.4466 , | 0.6755 ) |
| 0.090 | 0.5867 | ( 0.4726 , | 0.6939 ) |
| 0.100 | 0.6076 | ( 0.4964 , | 0.7107 ) |
| 0.110 | 0.6268 | ( 0.5183 , | 0.7261 ) |
| 0.120 | 0.6445 | ( 0.5385 , | 0.7403 ) |
| 0.130 | 0.6608 | ( 0.5572 , | 0.7535 ) |
| 0.140 | 0.6761 | ( 0.5747 , | 0.7658 ) |
| 0.150 | 0.6904 | ( 0.5911 , | 0.7774 ) |
| 0.200 | 0.7501 | ( 0.6593 , | 0.8261 ) |
| 0.250 | 0.7960 | ( 0.7115 , | 0.8636 ) |
| 0.300 | 0.8325 | ( 0.7532 , | 0.8932 ) |
| 0.400 | 0.8871 | ( 0.8166 , | 0.9358 ) |
| 0.500 | 0.9254 | ( 0.8633 , | 0.9632 ) |
| 0.600 | 0.9528 | ( 0.9000 , | 0.9805 ) |
| 0.700 | 0.9726 | ( 0.9300 , | 0.9910 ) |
| 0.800 | 0.9864 | ( 0.9552 , | 0.9967 ) |
| 0.900 | 0.9955 | ( 0.9773 , | 0.9994 ) |
| 0.950 | 0.9984 | ( 0.9877 , | 0.9999 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0042, 0.1675) | (0.0007, 0.0718) | (0.0182, 0.3207) |
| (0.0462, 0.4631) | (0.0230, 0.3527) | (0.0853, 0.5763) |
| (0.1023, 0.6122) | (0.0642, 0.5221) | (0.1546, 0.6967) |
| (0.4504, 0.9080) | (0.3723, 0.8739) | (0.5305, 0.9347) |

# APPENDIX IV

# B V

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 6, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 59.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 51. | 88. | 6. | 2. | 2. |
| ACTUALLY POSITIVE CASES | 4. | 6. | 8. | 13. | 28. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0134 0.0268 0.0671 0.6577 1.0000
TPF: 0.0000 0.4746 0.6949 0.8305 0.9322 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.3876 B= 0.5072
Z(K)= -0.4058 1.4979 1.9297 2.2142
LOGL= -231.0280
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 9 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.5292 B= 0.5732
Z(K)= -0.3860 1.3887 1.9468 2.6902
LOGL= -223.1701
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0608 | 0.0217 | 0.0050 | 0.0064 | 0.0019 | -0.0134 |
| B | 0.0217 | 0.0157 | 0.0018 | -0.0021 | -0.0091 | -0.0270 |
| Z( 1) | 0.0050 | 0.0018 | 0.0111 | 0.0037 | 0.0025 | 0.0006 |
| Z( 2) | 0.0064 | -0.0021 | 0.0037 | 0.0207 | 0.0189 | 0.0202 |
| Z( 3) | 0.0019 | -0.0091 | 0.0025 | 0.0189 | 0.0394 | 0.0462 |
| Z( 4) | -0.0134 | -0.0270 | 0.0006 | 0.0202 | 0.0462 | 0.1115 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.7016 | 0.1930 | 0.1810 | 0.0391 | -0.1623 |
| B | 0.7016 | 1.0000 | 0.1340 | -0.1160 | -0.3673 | -0.6461 |
| Z( 1) | 0.1930 | 0.1340 | 1.0000 | 0.2411 | 0.1213 | 0.0172 |
| Z( 2) | 0.1810 | -0.1160 | 0.2411 | 1.0000 | 0.6625 | 0.4205 |
| Z( 3) | 0.0391 | -0.3673 | 0.1213 | 0.6625 | 1.0000 | 0.6968 |
| Z( 4) | -0.1623 | -0.6461 | 0.0172 | 0.4205 | 0.6968 | 1.0000 |

AREA = 0.9077 STD. DEV.(AREA) = 0.0284

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.5209 | ( 0.3446 | , | 0.6932 ) |
| 0.010 | 0.5775 | ( 0.4129 | , | 0.7293 ) |
| 0.020 | 0.6375 | ( 0.4879 | , | 0.7684 ) |
| 0.030 | 0.6739 | ( 0.5339 | , | 0.7929 ) |
| 0.040 | 0.7004 | ( 0.5672 | , | 0.8110 ) |
| 0.050 | 0.7211 | ( 0.5932 | , | 0.8255 ) |
| 0.060 | 0.7382 | ( 0.6144 | , | 0.8376 ) |
| 0.070 | 0.7527 | ( 0.6323 | , | 0.8481 ) |
| 0.080 | 0.7654 | ( 0.6477 | , | 0.8572 ) |
| 0.090 | 0.7765 | ( 0.6613 | , | 0.8654 ) |
| 0.100 | 0.7865 | ( 0.6734 | , | 0.8728 ) |
| 0.110 | 0.7956 | ( 0.6842 | , | 0.8795 ) |
| 0.120 | 0.8039 | ( 0.6941 | , | 0.8856 ) |
| 0.130 | 0.8115 | ( 0.7032 | , | 0.8913 ) |
| 0.140 | 0.8186 | ( 0.7115 | , | 0.8965 ) |
| 0.150 | 0.8251 | ( 0.7192 | , | 0.9014 ) |
| 0.200 | 0.8524 | ( 0.7511 | , | 0.9216 ) |
| 0.250 | 0.8734 | ( 0.7755 | , | 0.9368 ) |
| 0.300 | 0.8904 | ( 0.7954 | , | 0.9487 ) |
| 0.400 | 0.9168 | ( 0.8270 | , | 0.9661 ) |
| 0.500 | 0.9369 | ( 0.8522 | , | 0.9779 ) |
| 0.600 | 0.9529 | ( 0.8740 | , | 0.9862 ) |
| 0.700 | 0.9663 | ( 0.8941 | , | 0.9920 ) |
| 0.800 | 0.9779 | ( 0.9141 | , | 0.9961 ) |
| 0.900 | 0.9882 | ( 0.9364 | , | 0.9987 ) |
| 0.950 | 0.9933 | ( 0.9509 | , | 0.9995 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0036, 0.4949) | (0.0004, 0.3490) | (0.0209, 0.6414) |
| (0.0258, 0.6603) | (0.0098, 0.5755) | (0.0596, 0.7376) |
| (0.0825, 0.7683) | (0.0474, 0.7161) | (0.1343, 0.8146) |
| (0.6503, 0.9600) | (0.5713, 0.9487) | (0.7232, 0.9692) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 6, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 82.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 46. | 87. | 8. | 5. | 3. |
| ACTUALLY POSITIVE CASES | 6. | 11. | 5. | 14. | 46. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0201 0.0537 0.1074 0.6913 1.0000

TPF: 0.0000 0.5610 0.7317 0.7927 0.9268 1.0000

INITIAL VALUES OF PARAMETERS:

A= 1.2746 B= 0.4676

Z(K)= -0.4991 1.2407 1.6104 2.0514

LOGL= -260.5021

CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:

A= 1.3109 B= 0.4987

Z(K)= -0.4857 1.1876 1.5601 2.2769

LOGL= -257.8493

CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0341 | 0.0109 | 0.0044 | 0.0046 | 0.0036 | -0.0012 |
| B | 0.0109 | 0.0093 | 0.0017 | -0.0015 | -0.0040 | -0.0132 |
| Z( 1) | 0.0044 | 0.0017 | 0.0114 | 0.0038 | 0.0030 | 0.0012 |
| Z( 2) | 0.0046 | -0.0015 | 0.0038 | 0.0168 | 0.0154 | 0.0153 |
| Z( 3) | 0.0036 | -0.0040 | 0.0030 | 0.0154 | 0.0239 | 0.0250 |
| Z( 4) | -0.0012 | -0.0132 | 0.0012 | 0.0153 | 0.0250 | 0.0613 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.6111 | 0.2221 | 0.1916 | 0.1275 | -0.0269 |
| B | 0.6111 | 1.0000 | 0.1647 | -0.1178 | -0.2656 | -0.5533 |
| Z( 1) | 0.2221 | 0.1647 | 1.0000 | 0.2735 | 0.1818 | 0.0462 |
| Z( 2) | 0.1916 | -0.1178 | 0.2735 | 1.0000 | 0.7662 | 0.4750 |
| Z( 3) | 0.1275 | -0.2656 | 0.1818 | 0.7662 | 1.0000 | 0.6528 |
| Z( 4) | -0.0269 | -0.5533 | 0.0462 | 0.4750 | 0.6528 | 1.0000 |

AREA = 0.8796 STD. DEV.(AREA) = 0.0285

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.5104 | ( 0.3577 , | 0.6616 ) |
| 0.010 | 0.5598 | ( 0.4169 , | 0.6953 ) |
| 0.020 | 0.6127 | ( 0.4819 , | 0.7318 ) |
| 0.030 | 0.6453 | ( 0.5224 , | 0.7547 ) |
| 0.040 | 0.6692 | ( 0.5520 , | 0.7717 ) |
| 0.050 | 0.6881 | ( 0.5754 , | 0.7855 ) |
| 0.060 | 0.7038 | ( 0.5947 , | 0.7970 ) |
| 0.070 | 0.7173 | ( 0.6112 , | 0.8071 ) |
| 0.080 | 0.7291 | ( 0.6255 , | 0.8160 ) |
| 0.090 | 0.7396 | ( 0.6382 , | 0.8240 ) |
| 0.100 | 0.7491 | ( 0.6496 , | 0.8313 ) |
| 0.110 | 0.7578 | ( 0.6599 , | 0.8379 ) |
| 0.120 | 0.7657 | ( 0.6694 , | 0.8441 ) |
| 0.130 | 0.7731 | ( 0.6781 , | 0.8499 ) |
| 0.140 | 0.7800 | ( 0.6861 , | 0.8553 ) |
| 0.150 | 0.7864 | ( 0.6936 , | 0.8603 ) |
| 0.200 | 0.8136 | ( 0.7250 , | 0.8819 ) |
| 0.250 | 0.8351 | ( 0.7495 , | 0.8991 ) |
| 0.300 | 0.8530 | ( 0.7697 , | 0.9133 ) |

| | | | | | |
|---|---|---|---|---|---|
| 0.400 | 0.8819 | ( | 0.8022 | , 0.9357 | ) |
| 0.500 | 0.9051 | ( | 0.8286 | , 0.9528 | ) |
| 0.600 | 0.9246 | ( | 0.8517 | , 0.9664 | ) |
| 0.700 | 0.9421 | ( | 0.8733 | , 0.9774 | ) |
| 0.800 | 0.9582 | ( | 0.8951 | , 0.9863 | ) |
| 0.900 | 0.9744 | ( | 0.9200 | , 0.9937 | ) |
| 0.950 | 0.9835 | ( | 0.9366 | , 0.9969 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0114, 0.5696) | (0.0029, 0.4735) | (0.0366, 0.6618) |
| (0.0594, 0.7029) | (0.0312, 0.6487) | (0.1043, 0.7530) |
| (0.1175, 0.7638) | (0.0747, 0.7230) | (0.1753, 0.8011) |
| (0.6864, 0.9398) | (0.6088, 0.9263) | (0.7565, 0.9513) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 6, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 27.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 42. | 87. | 7. | 12. | 1. |
| ACTUALLY POSITIVE CASES | 2. | 9. | 5. | 7. | 4. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0067 0.0872 0.1342 0.7181 1.0000
TPF: 0.0000 0.1481 0.4074 0.5926 0.9259 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.9964 B= 0.8218
Z(K)= -0.5769 1.1067 1.3581 2.4728
LOGL= -198.7468
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.0463 B= 0.8553
Z(K)= -0.5722 1.0813 1.4054 2.4435
LOGL= -198.2965
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0833 | 0.0310 | 0.0072 | 0.0082 | 0.0068 | -0.0055 |

| | | | | | | |
|---|---|---|---|---|---|---|
| B | 0.0310 | 0.0312 | 0.0029 | -0.0019 | -0.0051 | -0.0270 |
| Z( 1) | 0.0072 | 0.0029 | 0.0118 | 0.0037 | 0.0031 | 0.0008 |
| Z( 2) | 0.0082 | -0.0019 | 0.0037 | 0.0156 | 0.0140 | 0.0129 |
| Z( 3) | 0.0068 | -0.0051 | 0.0031 | 0.0140 | 0.0207 | 0.0199 |
| Z( 4) | -0.0055 | -0.0270 | 0.0008 | 0.0129 | 0.0199 | 0.0889 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.6084 | 0.2307 | 0.2287 | 0.1637 | -0.0639 |
| B | 0.6084 | 1.0000 | 0.1536 | -0.0877 | -0.2004 | -0.5135 |
| Z( 1) | 0.2307 | 0.1536 | 1.0000 | 0.2763 | 0.1981 | 0.0251 |
| Z( 2) | 0.2287 | -0.0877 | 0.2763 | 1.0000 | 0.7777 | 0.3453 |
| Z( 3) | 0.1637 | -0.2004 | 0.1981 | 0.7777 | 1.0000 | 0.4639 |
| Z( 4) | -0.0639 | -0.5135 | 0.0251 | 0.3453 | 0.4639 | 1.0000 |

AREA = 0.7867 STD. DEV.(AREA) = 0.0540

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1236 | ( 0.0311 , | 0.3266 ) |
| 0.010 | 0.1726 | ( 0.0562 , | 0.3819 ) |
| 0.020 | 0.2386 | ( 0.0985 , | 0.4479 ) |
| 0.030 | 0.2868 | ( 0.1343 , | 0.4924 ) |
| 0.040 | 0.3258 | ( 0.1657 , | 0.5272 ) |
| 0.050 | 0.3591 | ( 0.1940 , | 0.5562 ) |
| 0.060 | 0.3883 | ( 0.2198 , | 0.5813 ) |
| 0.070 | 0.4144 | ( 0.2435 , | 0.6036 ) |
| 0.080 | 0.4381 | ( 0.2655 , | 0.6237 ) |
| 0.090 | 0.4599 | ( 0.2859 , | 0.6421 ) |
| 0.100 | 0.4801 | ( 0.3051 , | 0.6590 ) |
| 0.110 | 0.4988 | ( 0.3231 , | 0.6748 ) |
| 0.120 | 0.5164 | ( 0.3401 , | 0.6895 ) |
| 0.130 | 0.5330 | ( 0.3563 , | 0.7034 ) |
| 0.140 | 0.5487 | ( 0.3716 , | 0.7164 ) |
| 0.150 | 0.5635 | ( 0.3861 , | 0.7288 ) |
| 0.200 | 0.6280 | ( 0.4501 , | 0.7819 ) |
| 0.250 | 0.6807 | ( 0.5029 , | 0.8244 ) |
| 0.300 | 0.7251 | ( 0.5479 , | 0.8590 ) |
| 0.400 | 0.7967 | ( 0.6228 , | 0.9110 ) |
| 0.500 | 0.8523 | ( 0.6846 , | 0.9465 ) |
| 0.600 | 0.8966 | ( 0.7388 , | 0.9703 ) |
| 0.700 | 0.9325 | ( 0.7891 , | 0.9856 ) |
| 0.800 | 0.9613 | ( 0.8384 , | 0.9945 ) |
| 0.900 | 0.9839 | ( 0.8917 , | 0.9989 ) |
| 0.950 | 0.9929 | ( 0.9244 , | 0.9997 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0073, 0.1483) | (0.0012, 0.0613) | (0.0315, 0.2933) |

```
(0.0800, 0.4381)          (0.0458, 0.3457)     (0.1306, 0.5340)
(0.1398, 0.5483)          (0.0924, 0.4650)     (0.2014, 0.6296)
(0.7164, 0.9377)          (0.6402, 0.9120)     (0.7839, 0.9571)
1                      R O C F I T (JUNE 1993 VERSION) :

 M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
           F R O M   R A T I N G   D A T A


  DATA DESCRIPTION: Reader 6, Benign or Malignant

  DATA COLLECTED IN  5 CATEGORIES
  WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

  NO. OF ACTUALLY NEGATIVE CASES =  149.     NO. OF ACTUALLY POSITIVE CASES =  150.

  RESPONSE DATA:
   CATEGORY                    1      2      3      4      5
   ACTUALLY NEGATIVE CASES    10.   121.    17.     1.     0.
   ACTUALLY POSITIVE CASES     1.    31.    71.    32.    15.

  OBSERVED OPERATING POINTS:
   FPF: 0.0000 0.0000 0.0067 0.1208 0.9329 1.0000
   TPF: 0.0000 0.1000 0.3133 0.7867 0.9933 1.0000

         INITIAL VALUES OF PARAMETERS:
  A=  1.3830    B=  0.8297
  Z(K)= -1.4979    1.1711    2.4728    2.7112
  LOGL=  -313.1151
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

  PROCEDURE CONVERGES AFTER   7 ITERATIONS.

         FINAL VALUES OF PARAMETERS:
  A=  1.6109    B=  0.7475
  Z(K)= -1.4729    1.1370    2.7862    3.8593
  LOGL=  -285.8086
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

         VARIANCE-COVARIANCE MATRIX:
  A       0.0461  0.0232  0.0070  0.0102 -0.0279 -0.0598
  B       0.0232  0.0210  0.0041 -0.0013 -0.0444 -0.0753
  Z( 1)   0.0070  0.0041  0.0238  0.0026 -0.0055 -0.0113
  Z( 2)   0.0102 -0.0013  0.0026  0.0165  0.0181  0.0200
  Z( 3)  -0.0279 -0.0444 -0.0055  0.0181  0.1331  0.1946
  Z( 4)  -0.0598 -0.0753 -0.0113  0.0200  0.1946  0.3304

         CORRELATION MATRIX:
  A       1.0000  0.7445  0.2125  0.3717 -0.3564 -0.4846
  B       0.7445  1.0000  0.1815 -0.0677 -0.8396 -0.9048
  Z( 1)   0.2125  0.1815  1.0000  0.1322 -0.0969 -0.1278
  Z( 2)   0.3717 -0.0677  0.1322  1.0000  0.3857  0.2706
  Z( 3)  -0.3564 -0.8396 -0.0969  0.3857  1.0000  0.9278
  Z( 4)  -0.4846 -0.9048 -0.1278  0.2706  0.9278  1.0000

       AREA =  0.9015        STD. DEV.(AREA) =  0.0210
1
  ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
  BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
  TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.3764 | ( 0.2065 , | 0.5748 ) |
| 0.010 | 0.4489 | ( 0.2827 , | 0.6248 ) |
| 0.020 | 0.5300 | ( 0.3767 , | 0.6790 ) |
| 0.030 | 0.5811 | ( 0.4394 , | 0.7129 ) |
| 0.040 | 0.6187 | ( 0.4865 , | 0.7382 ) |
| 0.050 | 0.6484 | ( 0.5243 , | 0.7585 ) |
| 0.060 | 0.6731 | ( 0.5555 , | 0.7756 ) |
| 0.070 | 0.6941 | ( 0.5821 , | 0.7904 ) |
| 0.080 | 0.7124 | ( 0.6051 , | 0.8035 ) |
| 0.090 | 0.7286 | ( 0.6254 , | 0.8153 ) |
| 0.100 | 0.7431 | ( 0.6433 , | 0.8260 ) |
| 0.110 | 0.7561 | ( 0.6594 , | 0.8357 ) |
| 0.120 | 0.7681 | ( 0.6739 , | 0.8448 ) |
| 0.130 | 0.7790 | ( 0.6872 , | 0.8531 ) |
| 0.140 | 0.7891 | ( 0.6993 , | 0.8609 ) |
| 0.150 | 0.7985 | ( 0.7104 , | 0.8682 ) |
| 0.200 | 0.8369 | ( 0.7553 , | 0.8984 ) |
| 0.250 | 0.8658 | ( 0.7883 , | 0.9212 ) |
| 0.300 | 0.8886 | ( 0.8142 , | 0.9388 ) |
| 0.400 | 0.9225 | ( 0.8534 , | 0.9635 ) |
| 0.500 | 0.9464 | ( 0.8830 , | 0.9789 ) |
| 0.600 | 0.9641 | ( 0.9071 , | 0.9886 ) |
| 0.700 | 0.9774 | ( 0.9281 , | 0.9945 ) |
| 0.800 | 0.9875 | ( 0.9474 , | 0.9979 ) |
| 0.900 | 0.9949 | ( 0.9668 , | 0.9995 ) |
| 0.950 | 0.9977 | ( 0.9779 , | 0.9999 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0001, 0.1013) | (0.0000, 0.0172) | (0.0031, 0.3330) |
| (0.0027, 0.3185) | (0.0002, 0.1571) | (0.0192, 0.5250) |
| (0.1278, 0.7767) | (0.0825, 0.7166) | (0.1880, 0.8287) |
| (0.9296, 0.9967) | (0.8791, 0.9935) | (0.9621, 0.9983) |

# APPENDIX IV

# B VI

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 7, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 59.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 82. | 51. | 8. | 6. | 2. |
| ACTUALLY POSITIVE CASES | 1. | 8. | 4. | 9. | 37. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0134 0.0537 0.1074 0.4497 1.0000
TPF: 0.0000 0.6271 0.7797 0.8475 0.9831 1.0000

INITIAL VALUES OF PARAMETERS:
A= 2.1865 B= 0.8676
Z(K)= 0.1262 1.2407 1.6104 2.2142
LOGL= -220.2996
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 2.1233 B= 0.8333
Z(K)= 0.1238 1.2597 1.6061 2.1666
LOGL= -220.1214
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.1270 | 0.0611 | 0.0083 | 0.0099 | 0.0041 | -0.0168 |
| B | 0.0611 | 0.0430 | 0.0026 | -0.0018 | -0.0086 | -0.0286 |
| Z( 1) | 0.0083 | 0.0026 | 0.0106 | 0.0055 | 0.0046 | 0.0032 |
| Z( 2) | 0.0099 | -0.0018 | 0.0055 | 0.0180 | 0.0165 | 0.0161 |
| Z( 3) | 0.0041 | -0.0086 | 0.0046 | 0.0165 | 0.0253 | 0.0269 |
| Z( 4) | -0.0168 | -0.0286 | 0.0032 | 0.0161 | 0.0269 | 0.0560 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.8274 | 0.2270 | 0.2065 | 0.0715 | -0.1987 |
| B | 0.8274 | 1.0000 | 0.1239 | -0.0647 | -0.2618 | -0.5828 |
| Z( 1) | 0.2270 | 0.1239 | 1.0000 | 0.4000 | 0.2837 | 0.1313 |
| Z( 2) | 0.2065 | -0.0647 | 0.4000 | 1.0000 | 0.7723 | 0.5057 |
| Z( 3) | 0.0715 | -0.2618 | 0.2837 | 0.7723 | 1.0000 | 0.7138 |
| Z( 4) | -0.1987 | -0.5828 | 0.1313 | 0.5057 | 0.7138 | 1.0000 |

AREA = 0.9486 STD. DEV.(AREA) = 0.0174

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.4907 | ( 0.2628 | , | 0.7217 ) |
| 0.010 | 0.5732 | ( 0.3620 | , | 0.7648 ) |
| 0.020 | 0.6597 | ( 0.4772 | , | 0.8107 ) |
| 0.030 | 0.7108 | ( 0.5483 | , | 0.8389 ) |
| 0.040 | 0.7467 | ( 0.5986 | , | 0.8596 ) |
| 0.050 | 0.7741 | ( 0.6367 | , | 0.8759 ) |
| 0.060 | 0.7960 | ( 0.6669 | , | 0.8894 ) |
| 0.070 | 0.8142 | ( 0.6916 | , | 0.9008 ) |
| 0.080 | 0.8295 | ( 0.7122 | , | 0.9106 ) |
| 0.090 | 0.8428 | ( 0.7298 | , | 0.9192 ) |
| 0.100 | 0.8543 | ( 0.7450 | , | 0.9267 ) |
| 0.110 | 0.8646 | ( 0.7583 | , | 0.9334 ) |
| 0.120 | 0.8737 | ( 0.7701 | , | 0.9393 ) |
| 0.130 | 0.8819 | ( 0.7806 | , | 0.9446 ) |
| 0.140 | 0.8893 | ( 0.7901 | , | 0.9494 ) |
| 0.150 | 0.8961 | ( 0.7987 | , | 0.9537 ) |
| 0.200 | 0.9225 | ( 0.8325 | , | 0.9699 ) |
| 0.250 | 0.9408 | ( 0.8566 | , | 0.9802 ) |
| 0.300 | 0.9542 | ( 0.8751 | , | 0.9869 ) |
| 0.400 | 0.9721 | ( 0.9026 | , | 0.9943 ) |
| 0.500 | 0.9831 | ( 0.9229 | , | 0.9976 ) |
| 0.600 | 0.9902 | ( 0.9392 | , | 0.9991 ) |
| 0.700 | 0.9948 | ( 0.9532 | , | 0.9997 ) |
| 0.800 | 0.9976 | ( 0.9660 | , | 0.9999 ) |
| 0.900 | 0.9993 | ( 0.9785 | , | 1.0000 ) |
| 0.950 | 0.9998 | ( 0.9856 | , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0151, 0.6247) | (0.0043, 0.4726) | (0.0443, 0.7594) |
| (0.0541, 0.7837) | (0.0275, 0.7002) | (0.0978, 0.8520) |
| (0.1039, 0.8585) | (0.0639, 0.8035) | (0.1595, 0.9020) |
| (0.4507, 0.9783) | (0.3725, 0.9680) | (0.5310, 0.9857) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 7, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 82.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 98. | 39. | 2. | 5. | 5. |
| ACTUALLY POSITIVE CASES | 5. | 7. | 0. | 8. | 62. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0336 0.0671 0.0805 0.3423 1.0000

TPF: 0.0000 0.7561 0.8537 0.8537 0.9390 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.8145 B= 0.5476
Z(K)= 0.4058 1.4017 1.4979 1.8313
LOGL= -205.7691
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.8307 B= 0.5978
Z(K)= 0.4095 1.3735 1.4355 1.8921
LOGL= -204.5984
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0774 | 0.0364 | 0.0075 | 0.0040 | 0.0032 | -0.0060 |
| B | 0.0364 | 0.0270 | 0.0024 | -0.0042 | -0.0051 | -0.0154 |
| Z( 1) | 0.0075 | 0.0024 | 0.0112 | 0.0067 | 0.0065 | 0.0051 |
| Z( 2) | 0.0040 | -0.0042 | 0.0067 | 0.0202 | 0.0199 | 0.0195 |
| Z( 3) | 0.0032 | -0.0051 | 0.0065 | 0.0199 | 0.0215 | 0.0212 |
| Z( 4) | -0.0060 | -0.0154 | 0.0051 | 0.0195 | 0.0212 | 0.0394 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.7951 | 0.2546 | 0.1018 | 0.0795 | -0.1083 |
| B | 0.7951 | 1.0000 | 0.1361 | -0.1777 | -0.2116 | -0.4724 |
| Z( 1) | 0.2546 | 0.1361 | 1.0000 | 0.4468 | 0.4199 | 0.2418 |
| Z( 2) | 0.1018 | -0.1777 | 0.4468 | 1.0000 | 0.9569 | 0.6916 |
| Z( 3) | 0.0795 | -0.2116 | 0.4199 | 0.9569 | 1.0000 | 0.7298 |
| Z( 4) | -0.1083 | -0.4724 | 0.2418 | 0.6916 | 0.7298 | 1.0000 |

AREA = 0.9420 STD. DEV.(AREA) = 0.0190

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.6144 | ( 0.4107 , | 0.7902 ) |
| 0.010 | 0.6700 | ( 0.4929 , | 0.8153 ) |
| 0.020 | 0.7267 | ( 0.5796 , | 0.8425 ) |
| 0.030 | 0.7600 | ( 0.6305 , | 0.8598 ) |
| 0.040 | 0.7835 | ( 0.6658 , | 0.8728 ) |
| 0.050 | 0.8016 | ( 0.6924 , | 0.8833 ) |
| 0.060 | 0.8162 | ( 0.7135 , | 0.8923 ) |
| 0.070 | 0.8285 | ( 0.7307 , | 0.9000 ) |
| 0.080 | 0.8391 | ( 0.7452 , | 0.9069 ) |
| 0.090 | 0.8483 | ( 0.7576 , | 0.9131 ) |
| 0.100 | 0.8565 | ( 0.7683 , | 0.9186 ) |
| 0.110 | 0.8638 | ( 0.7778 , | 0.9237 ) |
| 0.120 | 0.8704 | ( 0.7862 , | 0.9283 ) |
| 0.130 | 0.8764 | ( 0.7937 , | 0.9326 ) |
| 0.140 | 0.8820 | ( 0.8005 , | 0.9365 ) |
| 0.150 | 0.8871 | ( 0.8067 , | 0.9402 ) |
| 0.200 | 0.9079 | ( 0.8313 , | 0.9551 ) |
| 0.250 | 0.9233 | ( 0.8491 , | 0.9658 ) |
| 0.300 | 0.9354 | ( 0.8630 , | 0.9739 ) |

| | | | | | |
|---|---|---|---|---|---|
| 0.400 | 0.9535 | ( | 0.8843 | , 0.9847 | ) |
| 0.500 | 0.9664 | ( | 0.9007 | , 0.9912 | ) |
| 0.600 | 0.9763 | ( | 0.9147 | , 0.9953 | ) |
| 0.700 | 0.9840 | ( | 0.9274 | , 0.9977 | ) |
| 0.800 | 0.9902 | ( | 0.9401 | , 0.9991 | ) |
| 0.900 | 0.9953 | ( | 0.9543 | , 0.9998 | ) |
| 0.950 | 0.9976 | ( | 0.9637 | , 0.9999 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0292, 0.7580) | (0.0113, 0.6798) | (0.0664, 0.8244) |
| (0.0756, 0.8346) | (0.0425, 0.7884) | (0.1255, 0.8738) |
| (0.0848, 0.8437) | (0.0493, 0.8005) | (0.1368, 0.8802) |
| (0.3411, 0.9436) | (0.2687, 0.9281) | (0.4199, 0.9564) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 7, FAS/AD

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 149. NO. OF ACTUALLY POSITIVE CASES = 27.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 87. | 40. | 6. | 12. | 4. |
| ACTUALLY POSITIVE CASES | 5. | 7. | 1. | 8. | 6. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0268 0.1074 0.1477 0.4161 1.0000
TPF: 0.0000 0.2222 0.5185 0.5556 0.8148 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.1369 B= 0.9553
Z(K)= 0.2115 1.0466 1.2407 1.9297
LOGL= -203.8137
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.1181 B= 0.9444
Z(K)= 0.2135 1.0427 1.2129 1.9635
LOGL= -203.6756
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:
A 0.1028 0.0501 0.0105 0.0077 0.0063 -0.0052

| | | | | | | |
|---|---|---|---|---|---|---|
| B | 0.0501 | 0.0503 | 0.0036 | -0.0028 | -0.0051 | -0.0218 |
| Z( 1) | 0.0105 | 0.0036 | 0.0107 | 0.0066 | 0.0061 | 0.0040 |
| Z( 2) | 0.0077 | -0.0028 | 0.0066 | 0.0149 | 0.0140 | 0.0123 |
| Z( 3) | 0.0063 | -0.0051 | 0.0061 | 0.0140 | 0.0171 | 0.0154 |
| Z( 4) | -0.0052 | -0.0218 | 0.0040 | 0.0123 | 0.0154 | 0.0438 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.6973 | 0.3172 | 0.1970 | 0.1497 | -0.0771 |
| B | 0.6973 | 1.0000 | 0.1548 | -0.1016 | -0.1732 | -0.4642 |
| Z( 1) | 0.3172 | 0.1548 | 1.0000 | 0.5240 | 0.4478 | 0.1836 |
| Z( 2) | 0.1970 | -0.1016 | 0.5240 | 1.0000 | 0.8780 | 0.4818 |
| Z( 3) | 0.1497 | -0.1732 | 0.4478 | 0.8780 | 1.0000 | 0.5624 |
| Z( 4) | -0.0771 | -0.4642 | 0.1836 | 0.4818 | 0.5624 | 1.0000 |

AREA = 0.7919 STD. DEV.(AREA) = 0.0521

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.0943 | ( 0.0161 , | 0.3129 ) |
| 0.010 | 0.1402 | ( 0.0346 , | 0.3663 ) |
| 0.020 | 0.2056 | ( 0.0709 , | 0.4306 ) |
| 0.030 | 0.2551 | ( 0.1050 , | 0.4746 ) |
| 0.040 | 0.2961 | ( 0.1368 , | 0.5094 ) |
| 0.050 | 0.3316 | ( 0.1664 , | 0.5388 ) |
| 0.060 | 0.3630 | ( 0.1940 , | 0.5645 ) |
| 0.070 | 0.3913 | ( 0.2197 , | 0.5876 ) |
| 0.080 | 0.4172 | ( 0.2439 , | 0.6087 ) |
| 0.090 | 0.4411 | ( 0.2665 , | 0.6281 ) |
| 0.100 | 0.4632 | ( 0.2878 , | 0.6462 ) |
| 0.110 | 0.4839 | ( 0.3078 , | 0.6632 ) |
| 0.120 | 0.5033 | ( 0.3268 , | 0.6793 ) |
| 0.130 | 0.5217 | ( 0.3447 , | 0.6944 ) |
| 0.140 | 0.5390 | ( 0.3616 , | 0.7088 ) |
| 0.150 | 0.5554 | ( 0.3777 , | 0.7225 ) |
| 0.200 | 0.6268 | ( 0.4474 , | 0.7821 ) |
| 0.250 | 0.6849 | ( 0.5036 , | 0.8299 ) |
| 0.300 | 0.7334 | ( 0.5506 , | 0.8685 ) |
| 0.400 | 0.8104 | ( 0.6265 , | 0.9245 ) |
| 0.500 | 0.8682 | ( 0.6878 , | 0.9596 ) |
| 0.600 | 0.9126 | ( 0.7410 , | 0.9807 ) |
| 0.700 | 0.9466 | ( 0.7901 , | 0.9922 ) |
| 0.800 | 0.9721 | ( 0.8384 , | 0.9977 ) |
| 0.900 | 0.9901 | ( 0.8907 , | 0.9997 ) |
| 0.950 | 0.9962 | ( 0.9231 , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0248, 0.2308) | (0.0088, 0.1306) | (0.0602, 0.3636) |

```
(0.1126, 0.4891)          (0.0709, 0.3939)     (0.1694, 0.5850)
(0.1485, 0.5531)          (0.1000, 0.4633)     (0.2108, 0.6402)
(0.4155, 0.8203)          (0.3386, 0.7658)     (0.4957, 0.8660)
1                      R O C F I T (JUNE 1993 VERSION) :

 M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
           F R O M   R A T I N G   D A T A


  DATA DESCRIPTION: Reader 7, Benign or Malignant

  DATA COLLECTED IN  5 CATEGORIES
  WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

  NO. OF ACTUALLY NEGATIVE CASES =  149.     NO. OF ACTUALLY POSITIVE CASES =  150.

  RESPONSE DATA:
   CATEGORY                    1      2      3      4      5
   ACTUALLY NEGATIVE CASES    43.    87.    19.     0.     0.
   ACTUALLY POSITIVE CASES     2.    24.    89.    24.    11.

  OBSERVED OPERATING POINTS:
   FPF: 0.0000 0.0000 0.0000 0.1275 0.7114 1.0000
   TPF: 0.0000 0.0733 0.2333 0.8267 0.9867 1.0000

        INITIAL VALUES OF PARAMETERS:
  A=  1.8003    B=  1.0541
  Z(K)= -0.5571    1.1383    2.6112    2.7112
  LOGL=  -343.1591
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

  PROCEDURE CONVERGES AFTER   7 ITERATIONS.

        FINAL VALUES OF PARAMETERS:
  A=  1.7862    B=  0.7355
  Z(K)= -0.5591    1.1430    3.4209    4.4039
  LOGL=  -311.2273
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

        VARIANCE-COVARIANCE MATRIX:
  A       0.0407  0.0213  0.0064  0.0068 -0.0468 -0.0744
  B       0.0213  0.0236  0.0032 -0.0046 -0.0791 -0.1112
  Z( 1)   0.0064  0.0032  0.0118  0.0036 -0.0060 -0.0102
  Z( 2)   0.0068 -0.0046  0.0036  0.0168  0.0303  0.0364
  Z( 3)  -0.0468 -0.0791 -0.0060  0.0303  0.3152  0.4174
  Z( 4)  -0.0744 -0.1112 -0.0102  0.0364  0.4174  0.5974

        CORRELATION MATRIX:
  A       1.0000  0.6882  0.2914  0.2582 -0.4137 -0.4775
  B       0.6882  1.0000  0.1894 -0.2296 -0.9163 -0.9358
  Z( 1)   0.2914  0.1894  1.0000  0.2550 -0.0979 -0.1216
  Z( 2)   0.2582 -0.2296  0.2550  1.0000  0.4159  0.3636
  Z( 3)  -0.4137 -0.9163 -0.0979  0.4159  1.0000  0.9618
  Z( 4)  -0.4775 -0.9358 -0.1216  0.3636  0.9618  1.0000

     AREA =  0.9249       STD. DEV.(AREA) =  0.0167
1
  ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
  BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
  TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.4568 | ( 0.2456 , | 0.6814 ) |
| 0.010 | 0.5299 | ( 0.3296 , | 0.7227 ) |
| 0.020 | 0.6085 | ( 0.4307 , | 0.7659 ) |
| 0.030 | 0.6564 | ( 0.4966 , | 0.7922 ) |
| 0.040 | 0.6909 | ( 0.5455 , | 0.8112 ) |
| 0.050 | 0.7178 | ( 0.5842 , | 0.8264 ) |
| 0.060 | 0.7397 | ( 0.6160 , | 0.8390 ) |
| 0.070 | 0.7582 | ( 0.6428 , | 0.8498 ) |
| 0.080 | 0.7742 | ( 0.6658 , | 0.8593 ) |
| 0.090 | 0.7882 | ( 0.6859 , | 0.8677 ) |
| 0.100 | 0.8006 | ( 0.7037 , | 0.8754 ) |
| 0.110 | 0.8117 | ( 0.7194 , | 0.8824 ) |
| 0.120 | 0.8217 | ( 0.7336 , | 0.8888 ) |
| 0.130 | 0.8309 | ( 0.7464 , | 0.8948 ) |
| 0.140 | 0.8393 | ( 0.7580 , | 0.9003 ) |
| 0.150 | 0.8471 | ( 0.7686 , | 0.9055 ) |
| 0.200 | 0.8785 | ( 0.8106 , | 0.9271 ) |
| 0.250 | 0.9015 | ( 0.8402 , | 0.9436 ) |
| 0.300 | 0.9194 | ( 0.8626 , | 0.9563 ) |
| 0.400 | 0.9452 | ( 0.8949 , | 0.9743 ) |
| 0.500 | 0.9630 | ( 0.9179 , | 0.9854 ) |
| 0.600 | 0.9757 | ( 0.9359 , | 0.9923 ) |
| 0.700 | 0.9851 | ( 0.9510 , | 0.9964 ) |
| 0.800 | 0.9919 | ( 0.9646 , | 0.9987 ) |
| 0.900 | 0.9968 | ( 0.9778 , | 0.9997 ) |
| 0.950 | 0.9986 | ( 0.9853 , | 0.9999 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0000, 0.0732) | (0.0000, 0.0051) | (0.0019, 0.3675) |
| (0.0003, 0.2328) | (0.0000, 0.0619) | (0.0102, 0.5317) |
| (0.1265, 0.8278) | (0.0812, 0.7760) | (0.1870, 0.8713) |
| (0.7120, 0.9860) | (0.6355, 0.9794) | (0.7799, 0.9907) |

# APPENDIX IV

# B VII

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 9, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

NO. OF ACTUALLY NEGATIVE CASES = 125. NO. OF ACTUALLY POSITIVE CASES = 51.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 87. | 25. | 13. | 0. | 0. |
| ACTUALLY POSITIVE CASES | 4. | 6. | 10. | 9. | 22. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0000 0.0000 0.1040 0.3040 1.0000
TPF: 0.0000 0.4314 0.6078 0.8039 0.9216 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.7240 B= 0.6484
Z(K)= 0.5125 1.2592 2.5525 2.6525
LOGL= -186.1320
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI

PROCEDURE CONVERGES AFTER 8 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.5837 B= 0.4840
Z(K)= 0.5062 1.3070 2.7322 3.6470
LOGL= -175.6608
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0885 | 0.0335 | 0.0074 | 0.0054 | -0.0349 | -0.0885 |
| B | 0.0335 | 0.0230 | 0.0020 | -0.0021 | -0.0488 | -0.0949 |
| Z( 1) | 0.0074 | 0.0020 | 0.0138 | 0.0091 | 0.0041 | 0.0004 |
| Z( 2) | 0.0054 | -0.0021 | 0.0091 | 0.0226 | 0.0227 | 0.0268 |
| Z( 3) | -0.0349 | -0.0488 | 0.0041 | 0.0227 | 0.2101 | 0.2978 |
| Z( 4) | -0.0885 | -0.0949 | 0.0004 | 0.0268 | 0.2978 | 0.5556 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.7424 | 0.2112 | 0.1205 | -0.2558 | -0.3991 |
| B | 0.7424 | 1.0000 | 0.1114 | -0.0941 | -0.7011 | -0.8390 |
| Z( 1) | 0.2112 | 0.1114 | 1.0000 | 0.5152 | 0.0759 | 0.0042 |
| Z( 2) | 0.1205 | -0.0941 | 0.5152 | 1.0000 | 0.3294 | 0.2388 |
| Z( 3) | -0.2558 | -0.7011 | 0.0759 | 0.3294 | 1.0000 | 0.8716 |
| Z( 4) | -0.3991 | -0.8390 | 0.0042 | 0.2388 | 0.8716 | 1.0000 |

AREA = 0.9230 STD. DEV.(AREA) = 0.0307

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.6318 | ( 0.4299 | , | 0.8024 ) |
| 0.010 | 0.6763 | ( 0.4955 | , | 0.8228 ) |
| 0.020 | 0.7222 | ( 0.5636 | , | 0.8458 ) |
| 0.030 | 0.7496 | ( 0.6035 | , | 0.8608 ) |
| 0.040 | 0.7692 | ( 0.6315 | , | 0.8721 ) |
| 0.050 | 0.7845 | ( 0.6527 | , | 0.8814 ) |
| 0.060 | 0.7970 | ( 0.6698 | , | 0.8893 ) |
| 0.070 | 0.8076 | ( 0.6839 | , | 0.8961 ) |
| 0.080 | 0.8169 | ( 0.6959 | , | 0.9022 ) |
| 0.090 | 0.8250 | ( 0.7063 | , | 0.9077 ) |
| 0.100 | 0.8323 | ( 0.7154 | , | 0.9127 ) |
| 0.110 | 0.8389 | ( 0.7236 | , | 0.9172 ) |
| 0.120 | 0.8449 | ( 0.7309 | , | 0.9214 ) |
| 0.130 | 0.8505 | ( 0.7375 | , | 0.9252 ) |
| 0.140 | 0.8556 | ( 0.7436 | , | 0.9288 ) |
| 0.150 | 0.8604 | ( 0.7492 | , | 0.9322 ) |
| 0.200 | 0.8803 | ( 0.7719 | , | 0.9460 ) |
| 0.250 | 0.8957 | ( 0.7890 | , | 0.9565 ) |
| 0.300 | 0.9082 | ( 0.8027 | , | 0.9648 ) |
| 0.400 | 0.9280 | ( 0.8242 | , | 0.9768 ) |
| 0.500 | 0.9434 | ( 0.8415 | , | 0.9849 ) |
| 0.600 | 0.9560 | ( 0.8566 | , | 0.9905 ) |
| 0.700 | 0.9669 | ( 0.8709 | , | 0.9945 ) |
| 0.800 | 0.9768 | ( 0.8857 | , | 0.9973 ) |
| 0.900 | 0.9862 | ( 0.9034 | , | 0.9991 ) |
| 0.950 | 0.9913 | ( 0.9160 | , | 0.9996 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0001, 0.4280) | (0.0000, 0.1871) | (0.0144, 0.7004) |
| (0.0031, 0.6030) | (0.0001, 0.4311) | (0.0333, 0.7568) |
| (0.0956, 0.8292) | (0.0546, 0.7906) | (0.1557, 0.8630) |
| (0.3064, 0.9097) | (0.2308, 0.8902) | (0.3912, 0.9265) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 9, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

NO. OF ACTUALLY NEGATIVE CASES = 125. NO. OF ACTUALLY POSITIVE CASES = 65.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 120. | 4. | 0. | 0. | 1. |
| ACTUALLY POSITIVE CASES | 23. | 0. | 2. | 5. | 35. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0080 0.0080 0.0080 0.0400 1.0000

TPF: 0.0000 0.5385 0.6154 0.6462 0.6462 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.3348 B= 0.4725
Z(K)= 1.7511 2.2093 2.3093 2.4093
LOGL= -98.6914
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI

PROCEDURE CONVERGES AFTER 8 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.8911 B= 0.2887
Z(K)= 1.7590 2.0535 2.2508 2.7339
LOGL= -94.1625
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.1439 | 0.0582 | 0.0187 | -0.0051 | -0.0258 | -0.0947 |
| B | 0.0582 | 0.0291 | 0.0038 | -0.0093 | -0.0206 | -0.0582 |
| Z( 1) | 0.0187 | 0.0038 | 0.0419 | 0.0377 | 0.0351 | 0.0291 |
| Z( 2) | -0.0051 | -0.0093 | 0.0377 | 0.0578 | 0.0596 | 0.0693 |
| Z( 3) | -0.0258 | -0.0206 | 0.0351 | 0.0596 | 0.0815 | 0.1048 |
| Z( 4) | -0.0947 | -0.0582 | 0.0291 | 0.0693 | 0.1048 | 0.2247 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.9004 | 0.2413 | -0.0564 | -0.2380 | -0.5266 |
| B | 0.9004 | 1.0000 | 0.1084 | -0.2260 | -0.4226 | -0.7202 |
| Z( 1) | 0.2413 | 0.1084 | 1.0000 | 0.7662 | 0.6009 | 0.2999 |
| Z( 2) | -0.0564 | -0.2260 | 0.7662 | 1.0000 | 0.8682 | 0.6084 |
| Z( 3) | -0.2380 | -0.4226 | 0.6009 | 0.8682 | 1.0000 | 0.7746 |
| Z( 4) | -0.5266 | -0.7202 | 0.2999 | 0.6084 | 0.7746 | 1.0000 |

AREA = 0.8040 STD. DEV.(AREA) = 0.0912

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.5585 | ( 0.4096 , | 0.6995 ) |
| 0.010 | 0.5868 | ( 0.4516 , | 0.7123 ) |
| 0.020 | 0.6171 | ( 0.4897 , | 0.7330 ) |
| 0.030 | 0.6360 | ( 0.5087 , | 0.7498 ) |
| 0.040 | 0.6501 | ( 0.5204 , | 0.7642 ) |
| 0.050 | 0.6613 | ( 0.5284 , | 0.7767 ) |
| 0.060 | 0.6708 | ( 0.5341 , | 0.7877 ) |
| 0.070 | 0.6790 | ( 0.5384 , | 0.7976 ) |
| 0.080 | 0.6863 | ( 0.5418 , | 0.8066 ) |
| 0.090 | 0.6928 | ( 0.5446 , | 0.8148 ) |
| 0.100 | 0.6988 | ( 0.5468 , | 0.8224 ) |
| 0.110 | 0.7043 | ( 0.5486 , | 0.8294 ) |
| 0.120 | 0.7094 | ( 0.5501 , | 0.8358 ) |
| 0.130 | 0.7142 | ( 0.5515 , | 0.8419 ) |
| 0.140 | 0.7188 | ( 0.5526 , | 0.8476 ) |
| 0.150 | 0.7230 | ( 0.5535 , | 0.8529 ) |
| 0.200 | 0.7415 | ( 0.5567 , | 0.8756 ) |
| 0.250 | 0.7569 | ( 0.5584 , | 0.8936 ) |
| 0.300 | 0.7703 | ( 0.5592 , | 0.9083 ) |

```
   0.400    0.7933      (   0.5595  ,   0.9314   )
   0.500    0.8136      (   0.5587  ,   0.9489   )
   0.600    0.8325      (   0.5571  ,   0.9628   )
   0.700    0.8514      (   0.5549  ,   0.9742   )
   0.800    0.8716      (   0.5517  ,   0.9837   )
   0.900    0.8964      (   0.5465  ,   0.9919   )
   0.950    0.9140      (   0.5417  ,   0.9957   )
```

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0031, 0.5405) | (0.0001, 0.4339) | (0.0355, 0.6443) |
| (0.0122, 0.5953) | (0.0025, 0.5317) | (0.0454, 0.6564) |
| (0.0200, 0.6172) | (0.0058, 0.5644) | (0.0568, 0.6679) |
| (0.0393, 0.6492) | (0.0154, 0.6054) | (0.0872, 0.6911) |

```
1                        R O C F I T (JUNE 1993 VERSION) :

      M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
           O F   A   B I N O R M A L   R O C   C U R V E
                F R O M   R A T I N G   D A T A

 DATA DESCRIPTION: Reader 9, FAS/AD

 DATA COLLECTED IN  5 CATEGORIES
 WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

 NO. OF ACTUALLY NEGATIVE CASES =  125.     NO. OF ACTUALLY POSITIVE CASES =   27.

 RESPONSE DATA:
  CATEGORY                    1     2     3     4     5
  ACTUALLY NEGATIVE CASES   110.    10.    4.    0.    1.
  ACTUALLY POSITIVE CASES    14.     2.    2.    6.    3.

 OBSERVED OPERATING POINTS:
  FPF: 0.0000 0.0080 0.0080 0.0400 0.1200 1.0000
  TPF: 0.0000 0.1111 0.3333 0.4074 0.4815 1.0000

        INITIAL VALUES OF PARAMETERS:
 A=  0.9060    B=  0.7267
 Z(K)=  1.1751    1.7511    2.3093    2.4093
 LOGL=  -104.1775
 CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI


 PROCEDURE CONVERGES AFTER   9 ITERATIONS.


        FINAL VALUES OF PARAMETERS:
 A=  0.7393    B=  0.6325
 Z(K)=  1.1833    1.6786    2.1371    2.9004
 LOGL=   -96.8623
 CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI


        VARIANCE-COVARIANCE MATRIX:
 A       0.2046  0.0948  0.0185  0.0021 -0.0236 -0.1023
```

| | | | | | | |
|---|---|---|---|---|---|---|
| B | 0.0948 | 0.0614 | 0.0043 | -0.0083 | -0.0279 | -0.0864 |
| Z( 1) | 0.0185 | 0.0043 | 0.0213 | 0.0172 | 0.0144 | 0.0097 |
| Z( 2) | 0.0021 | -0.0083 | 0.0172 | 0.0338 | 0.0328 | 0.0381 |
| Z( 3) | -0.0236 | -0.0279 | 0.0144 | 0.0328 | 0.0676 | 0.0869 |
| Z( 4) | -0.1023 | -0.0864 | 0.0097 | 0.0381 | 0.0869 | 0.2634 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.8458 | 0.2800 | 0.0251 | -0.2005 | -0.4407 |
| B | 0.8458 | 1.0000 | 0.1192 | -0.1824 | -0.4333 | -0.6794 |
| Z( 1) | 0.2800 | 0.1192 | 1.0000 | 0.6440 | 0.3785 | 0.1302 |
| Z( 2) | 0.0251 | -0.1824 | 0.6440 | 1.0000 | 0.6866 | 0.4042 |
| Z( 3) | -0.2005 | -0.4333 | 0.3785 | 0.6866 | 1.0000 | 0.6512 |
| Z( 4) | -0.4407 | -0.6794 | 0.1302 | 0.4042 | 0.6512 | 1.0000 |

AREA = 0.7339 STD. DEV.(AREA) = 0.1068

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1867 | ( 0.0572 , | 0.4202 ) |
| 0.010 | 0.2319 | ( 0.0903 , | 0.4499 ) |
| 0.020 | 0.2877 | ( 0.1370 , | 0.4895 ) |
| 0.030 | 0.3261 | ( 0.1708 , | 0.5199 ) |
| 0.040 | 0.3563 | ( 0.1972 , | 0.5459 ) |
| 0.050 | 0.3816 | ( 0.2186 , | 0.5691 ) |
| 0.060 | 0.4035 | ( 0.2366 , | 0.5904 ) |
| 0.070 | 0.4229 | ( 0.2519 , | 0.6102 ) |
| 0.080 | 0.4405 | ( 0.2652 , | 0.6286 ) |
| 0.090 | 0.4566 | ( 0.2769 , | 0.6459 ) |
| 0.100 | 0.4715 | ( 0.2873 , | 0.6622 ) |
| 0.110 | 0.4854 | ( 0.2966 , | 0.6776 ) |
| 0.120 | 0.4984 | ( 0.3051 , | 0.6921 ) |
| 0.130 | 0.5107 | ( 0.3128 , | 0.7059 ) |
| 0.140 | 0.5223 | ( 0.3199 , | 0.7190 ) |
| 0.150 | 0.5334 | ( 0.3264 , | 0.7315 ) |
| 0.200 | 0.5820 | ( 0.3533 , | 0.7854 ) |
| 0.250 | 0.6228 | ( 0.3739 , | 0.8282 ) |
| 0.300 | 0.6583 | ( 0.3908 , | 0.8628 ) |
| 0.400 | 0.7188 | ( 0.4183 , | 0.9138 ) |
| 0.500 | 0.7701 | ( 0.4414 , | 0.9480 ) |
| 0.600 | 0.8157 | ( 0.4628 , | 0.9707 ) |
| 0.700 | 0.8579 | ( 0.4843 , | 0.9854 ) |
| 0.800 | 0.8982 | ( 0.5081 , | 0.9942 ) |
| 0.900 | 0.9394 | ( 0.5393 , | 0.9987 ) |
| 0.950 | 0.9625 | ( 0.5638 , | 0.9997 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0019, 0.1367) | (0.0000, 0.0417) | (0.0291, 0.3231) |

```
(0.0163, 0.2701)          (0.0041, 0.1749)     (0.0518, 0.3859)
(0.0466, 0.3735)          (0.0207, 0.2911)     (0.0937, 0.4623)
(0.1183, 0.4963)          (0.0709, 0.4247)     (0.1847, 0.5681)
1                    R O C F I T (JUNE 1993 VERSION) :

 M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
      O F   A   B I N O R M A L   R O C   C U R V E
           F R O M   R A T I N G   D A T A


  DATA DESCRIPTION: Reader 9, Benign or Malignant

  DATA COLLECTED IN  5 CATEGORIES
  WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMAL

  NO. OF ACTUALLY NEGATIVE CASES =  125.     NO. OF ACTUALLY POSITIVE CASES =  125.

  RESPONSE DATA:
   CATEGORY                    1      2      3      4      5
   ACTUALLY NEGATIVE CASES    74.    45.     6.     0.     0.
   ACTUALLY POSITIVE CASES    14.    35.    54.    10.    12.

  OBSERVED OPERATING POINTS:
   FPF: 0.0000 0.0000 0.0000 0.0480 0.4080 1.0000
   TPF: 0.0000 0.0960 0.1760 0.6080 0.8880 1.0000

         INITIAL VALUES OF PARAMETERS:
  A=  1.5928    B=  1.0021
  Z(K)=  0.2323    1.6649    2.5525    2.6525
  LOGL=  -291.5787
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI


  PROCEDURE CONVERGES AFTER   6 ITERATIONS.


         FINAL VALUES OF PARAMETERS:
  A=  1.3650    B=  0.6517
  Z(K)=  0.2320    1.6703    3.5245    4.0979
  LOGL=  -276.9216
  CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARI


         VARIANCE-COVARIANCE MATRIX:
  A       0.0333  0.0153  0.0090  0.0013 -0.0356 -0.0483
  B       0.0153  0.0162  0.0030 -0.0129 -0.0612 -0.0759
  Z( 1)   0.0090  0.0030  0.0128  0.0060 -0.0025 -0.0052
  Z( 2)   0.0013 -0.0129  0.0060  0.0358  0.0715  0.0829
  Z( 3)  -0.0356 -0.0612 -0.0025  0.0715  0.2948  0.3453
  Z( 4)  -0.0483 -0.0759 -0.0052  0.0829  0.3453  0.4386


         CORRELATION MATRIX:
  A       1.0000  0.6584  0.4356  0.0388 -0.3594 -0.4000
  B       0.6584  1.0000  0.2100 -0.5363 -0.8854 -0.9004
  Z( 1)   0.4356  0.2100  1.0000  0.2790 -0.0408 -0.0689
  Z( 2)   0.0388 -0.5363  0.2790  1.0000  0.6956  0.6613
  Z( 3)  -0.3594 -0.8854 -0.0408  0.6956  1.0000  0.9602
  Z( 4)  -0.4000 -0.9004 -0.0689  0.6613  0.9602  1.0000


       AREA =  0.8736        STD. DEV.(AREA) =  0.0249
1
  ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
  BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
  TRUE-POSITIVE FRACTION AT EACH SPECIFIED
```

FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.3767 | ( 0.2113 , | 0.5690 ) |
| 0.010 | 0.4398 | ( 0.2780 , | 0.6125 ) |
| 0.020 | 0.5104 | ( 0.3595 , | 0.6599 ) |
| 0.030 | 0.5552 | ( 0.4139 , | 0.6898 ) |
| 0.040 | 0.5885 | ( 0.4553 , | 0.7122 ) |
| 0.050 | 0.6151 | ( 0.4887 , | 0.7303 ) |
| 0.060 | 0.6374 | ( 0.5168 , | 0.7456 ) |
| 0.070 | 0.6565 | ( 0.5410 , | 0.7590 ) |
| 0.080 | 0.6733 | ( 0.5621 , | 0.7709 ) |
| 0.090 | 0.6883 | ( 0.5809 , | 0.7817 ) |
| 0.100 | 0.7018 | ( 0.5978 , | 0.7915 ) |
| 0.110 | 0.7141 | ( 0.6130 , | 0.8006 ) |
| 0.120 | 0.7254 | ( 0.6270 , | 0.8090 ) |
| 0.130 | 0.7359 | ( 0.6397 , | 0.8170 ) |
| 0.140 | 0.7456 | ( 0.6515 , | 0.8244 ) |
| 0.150 | 0.7547 | ( 0.6625 , | 0.8314 ) |
| 0.200 | 0.7929 | ( 0.7075 , | 0.8615 ) |
| 0.250 | 0.8227 | ( 0.7415 , | 0.8855 ) |
| 0.300 | 0.8470 | ( 0.7687 , | 0.9053 ) |
| 0.400 | 0.8850 | ( 0.8107 , | 0.9357 ) |
| 0.500 | 0.9139 | ( 0.8431 , | 0.9575 ) |
| 0.600 | 0.9370 | ( 0.8703 , | 0.9733 ) |
| 0.700 | 0.9560 | ( 0.8947 , | 0.9847 ) |
| 0.800 | 0.9721 | ( 0.9182 , | 0.9925 ) |
| 0.900 | 0.9861 | ( 0.9433 , | 0.9976 ) |
| 0.950 | 0.9926 | ( 0.9589 , | 0.9991 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0000, 0.0958) | (0.0000, 0.0157) | (0.0026, 0.3228) |
| (0.0002, 0.1756) | (0.0000, 0.0520) | (0.0069, 0.4058) |
| (0.0474, 0.6089) | (0.0206, 0.5138) | (0.0969, 0.6978) |
| (0.4083, 0.8876) | (0.3250, 0.8575) | (0.4959, 0.9128) |

# APPENDIX IV

# B VIII

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 10, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100. NO. OF ACTUALLY POSITIVE CASES = 42.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 94. | 4. | 1. | 0. | 1. |
| ACTUALLY POSITIVE CASES | 14. | 3. | 3. | 4. | 18. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0100 0.0100 0.0200 0.0600 1.0000
TPF: 0.0000 0.4286 0.5238 0.5952 0.6667 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.5622 B= 0.6980
Z(K)= 1.5551 2.0542 2.2268 2.3268
LOGL= -87.2521
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.4407 B= 0.6401
Z(K)= 1.5592 1.9417 2.2197 2.5170
LOGL= -84.9281
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.3827 | 0.1857 | 0.0387 | -0.0155 | -0.0682 | -0.1359 |
| B | 0.1857 | 0.1039 | 0.0084 | -0.0248 | -0.0567 | -0.0972 |
| Z( 1) | 0.0387 | 0.0084 | 0.0400 | 0.0346 | 0.0311 | 0.0273 |
| Z( 2) | -0.0155 | -0.0248 | 0.0346 | 0.0585 | 0.0639 | 0.0722 |
| Z( 3) | -0.0682 | -0.0567 | 0.0311 | 0.0639 | 0.0962 | 0.1157 |
| Z( 4) | -0.1359 | -0.0972 | 0.0273 | 0.0722 | 0.1157 | 0.1722 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.9310 | 0.3127 | -0.1038 | -0.3552 | -0.5292 |
| B | 0.9310 | 1.0000 | 0.1307 | -0.3180 | -0.5666 | -0.7266 |
| Z( 1) | 0.3127 | 0.1307 | 1.0000 | 0.7158 | 0.5011 | 0.3296 |
| Z( 2) | -0.1038 | -0.3180 | 0.7158 | 1.0000 | 0.8521 | 0.7189 |
| Z( 3) | -0.3552 | -0.5666 | 0.5011 | 0.8521 | 1.0000 | 0.8989 |
| Z( 4) | -0.5292 | -0.7266 | 0.3296 | 0.7189 | 0.8989 | 1.0000 |

AREA = 0.8875 STD. DEV.(AREA) = 0.0691

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | | UPPER BOUND) |
|---|---|---|---|---|
| 0.005 | 0.4174 | ( 0.1907 | , | 0.6767 ) |
| 0.010 | 0.4806 | ( 0.2717 | , | 0.6951 ) |
| 0.020 | 0.5500 | ( 0.3638 | , | 0.7256 ) |
| 0.030 | 0.5935 | ( 0.4167 | , | 0.7528 ) |
| 0.040 | 0.6254 | ( 0.4508 | , | 0.7773 ) |
| 0.050 | 0.6508 | ( 0.4744 | , | 0.7993 ) |
| 0.060 | 0.6719 | ( 0.4916 | , | 0.8190 ) |
| 0.070 | 0.6900 | ( 0.5046 | , | 0.8365 ) |
| 0.080 | 0.7058 | ( 0.5148 | , | 0.8520 ) |
| 0.090 | 0.7198 | ( 0.5230 | , | 0.8658 ) |
| 0.100 | 0.7324 | ( 0.5297 | , | 0.8782 ) |
| 0.110 | 0.7439 | ( 0.5353 | , | 0.8892 ) |
| 0.120 | 0.7544 | ( 0.5402 | , | 0.8990 ) |
| 0.130 | 0.7641 | ( 0.5443 | , | 0.9079 ) |
| 0.140 | 0.7731 | ( 0.5480 | , | 0.9159 ) |
| 0.150 | 0.7815 | ( 0.5512 | , | 0.9230 ) |
| 0.200 | 0.8165 | ( 0.5630 | , | 0.9501 ) |
| 0.250 | 0.8435 | ( 0.5708 | , | 0.9671 ) |
| 0.300 | 0.8655 | ( 0.5765 | , | 0.9782 ) |
| 0.400 | 0.8995 | ( 0.5845 | , | 0.9905 ) |
| 0.500 | 0.9252 | ( 0.5902 | , | 0.9960 ) |
| 0.600 | 0.9455 | ( 0.5948 | , | 0.9985 ) |
| 0.700 | 0.9621 | ( 0.5989 | , | 0.9995 ) |
| 0.800 | 0.9761 | ( 0.6029 | , | 0.9999 ) |
| 0.900 | 0.9881 | ( 0.6074 | , | 1.0000 ) |
| 0.950 | 0.9937 | ( 0.6105 | , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0059, 0.4323) | (0.0004, 0.2447) | (0.0442, 0.6369) |
| (0.0132, 0.5079) | (0.0023, 0.3559) | (0.0535, 0.6587) |
| (0.0261, 0.5784) | (0.0078, 0.4579) | (0.0711, 0.6919) |
| (0.0595, 0.6710) | (0.0255, 0.5760) | (0.1215, 0.7560) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 10, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100. NO. OF ACTUALLY POSITIVE CASES = 51.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 91. | 4. | 0. | 1. | 4. |
| ACTUALLY POSITIVE CASES | 18. | 4. | 0. | 5. | 24. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0400 0.0500 0.0900 1.0000

TPF: 0.0000 0.4706 0.5686 0.6471 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.7439 B= 1.0039
Z(K)= 1.3410 1.6452 1.7511
LOGL= -99.3411
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.7844 B= 1.0437
Z(K)= 1.3425 1.5801 1.7761
LOGL= -98.0825
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

VARIANCE-COVARIANCE MATRIX:

| | | | | | |
|---|---|---|---|---|---|
| A | 0.6934 | 0.4292 | 0.0497 | -0.0069 | -0.0612 |
| B | 0.4292 | 0.2914 | 0.0129 | -0.0273 | -0.0655 |
| Z( 1) | 0.0497 | 0.0129 | 0.0311 | 0.0281 | 0.0258 |
| Z( 2) | -0.0069 | -0.0273 | 0.0281 | 0.0370 | 0.0395 |
| Z( 3) | -0.0612 | -0.0655 | 0.0258 | 0.0395 | 0.0529 |

CORRELATION MATRIX:

| | | | | | |
|---|---|---|---|---|---|
| A | 1.0000 | 0.9547 | 0.3385 | -0.0433 | -0.3193 |
| B | 0.9547 | 1.0000 | 0.1350 | -0.2628 | -0.5272 |
| Z( 1) | 0.3385 | 0.1350 | 1.0000 | 0.8281 | 0.6350 |
| Z( 2) | -0.0433 | -0.2628 | 0.8281 | 1.0000 | 0.8929 |
| Z( 3) | -0.3193 | -0.5272 | 0.6350 | 0.8929 | 1.0000 |

AREA = 0.8915 STD. DEV.(AREA) = 0.0515

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1829 | ( 0.0150 , | 0.6407 ) |
| 0.010 | 0.2598 | ( 0.0475 , | 0.6488 ) |
| 0.020 | 0.3596 | ( 0.1264 , | 0.6644 ) |
| 0.030 | 0.4290 | ( 0.2035 , | 0.6813 ) |
| 0.040 | 0.4828 | ( 0.2705 , | 0.7002 ) |
| 0.050 | 0.5268 | ( 0.3258 , | 0.7211 ) |
| 0.060 | 0.5641 | ( 0.3699 , | 0.7437 ) |
| 0.070 | 0.5963 | ( 0.4045 , | 0.7672 ) |
| 0.080 | 0.6246 | ( 0.4313 , | 0.7906 ) |
| 0.090 | 0.6498 | ( 0.4521 , | 0.8133 ) |
| 0.100 | 0.6725 | ( 0.4684 , | 0.8346 ) |
| 0.110 | 0.6929 | ( 0.4813 , | 0.8543 ) |
| 0.120 | 0.7116 | ( 0.4917 , | 0.8722 ) |
| 0.130 | 0.7287 | ( 0.5002 , | 0.8882 ) |
| 0.140 | 0.7444 | ( 0.5072 , | 0.9025 ) |
| 0.150 | 0.7589 | ( 0.5131 , | 0.9151 ) |
| 0.200 | 0.8176 | ( 0.5321 , | 0.9584 ) |
| 0.250 | 0.8601 | ( 0.5423 , | 0.9801 ) |
| 0.300 | 0.8921 | ( 0.5487 , | 0.9907 ) |
| 0.400 | 0.9358 | ( 0.5563 , | 0.9981 ) |
| 0.500 | 0.9628 | ( 0.5605 , | 0.9997 ) |

```
   0.600    0.9797      (   0.5632  ,   1.0000   )
   0.700    0.9901      (   0.5650  ,   1.0000   )
   0.800    0.9961      (   0.5661  ,   1.0000   )
   0.900    0.9991      (   0.5665  ,   1.0000   )
   0.950    0.9998      (   0.5663  ,   1.0000   )



      ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
      CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
      CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:


 EXPECTED OPERATING POINT          LOWER BOUND          UPPER BOUND
     ( FPF ,   TPF )            ( FPF ,   TPF )      ( FPF ,   TPF )

     (0.0379, 0.4724)           (0.0130, 0.2946)     (0.0926, 0.6559)
     (0.0570, 0.5538)           (0.0252, 0.3981)     (0.1145, 0.7016)
     (0.0897, 0.6492)           (0.0457, 0.5090)     (0.1594, 0.7716)
1                           R O C F I T (JUNE 1993 VERSION) :

      M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
           O F   A   B I N O R M A L   R O C   C U R V E
                F R O M   R A T I N G   D A T A


      DATA DESCRIPTION: Reader 10, FAS/AD

      DATA COLLECTED IN  5 CATEGORIES
      WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

      NO. OF ACTUALLY NEGATIVE CASES =  100.     NO. OF ACTUALLY POSITIVE CASES =   23.

      RESPONSE DATA:
       CATEGORY                    1      2      3      4      5
       ACTUALLY NEGATIVE CASES    96.     2.     1.     1.     0.
       ACTUALLY POSITIVE CASES    20.     2.     0.     0.     1.

      OBSERVED OPERATING POINTS:
       FPF: 0.0000 0.0000 0.0100 0.0200 0.0400 1.0000
       TPF: 0.0000 0.0435 0.0435 0.0435 0.1304 1.0000

            INITIAL VALUES OF PARAMETERS:
      A=  0.0057    B=  0.6871
      Z(K)=  1.7511    2.0542    2.3268    2.5762
      LOGL=   -34.0185
      CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


      PROCEDURE CONVERGES AFTER   7 ITERATIONS.


            FINAL VALUES OF PARAMETERS:
      A=  0.1095    B=  0.7126
      Z(K)=  1.7463    2.1891    2.3811    2.7516
      LOGL=   -33.5911
      CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


            VARIANCE-COVARIANCE MATRIX:
      A       1.2379  0.5909  0.0566 -0.0612 -0.1250 -0.2807
      B       0.5909  0.3157  0.0114 -0.0532 -0.0884 -0.1745
      Z( 1)   0.0566  0.0114  0.0514  0.0437  0.0408  0.0356
      Z( 2)  -0.0612 -0.0532  0.0437  0.0968  0.0986  0.1071
```

| | | | | | | |
|---|---|---|---|---|---|---|
| Z( 3) | -0.1250 | -0.0884 | 0.0408 | 0.0986 | 0.1412 | 0.1559 |
| Z( 4) | -0.2807 | -0.1745 | 0.0356 | 0.1071 | 0.1559 | 0.3118 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.9453 | 0.2243 | -0.1767 | -0.2989 | -0.4518 |
| B | 0.9453 | 1.0000 | 0.0898 | -0.3045 | -0.4188 | -0.5560 |
| Z( 1) | 0.2243 | 0.0898 | 1.0000 | 0.6202 | 0.4794 | 0.2813 |
| Z( 2) | -0.1767 | -0.3045 | 0.6202 | 1.0000 | 0.8436 | 0.6162 |
| Z( 3) | -0.2989 | -0.4188 | 0.4794 | 0.8436 | 1.0000 | 0.7429 |
| Z( 4) | -0.4518 | -0.5560 | 0.2813 | 0.6162 | 0.7429 | 1.0000 |

AREA = 0.5355 STD. DEV.(AREA) = 0.3512

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.0421 | ( 0.0027 , | 0.2502 ) |
| 0.010 | 0.0607 | ( 0.0078 , | 0.2487 ) |
| 0.020 | 0.0878 | ( 0.0181 , | 0.2692 ) |
| 0.030 | 0.1091 | ( 0.0260 , | 0.3017 ) |
| 0.040 | 0.1275 | ( 0.0313 , | 0.3392 ) |
| 0.050 | 0.1439 | ( 0.0346 , | 0.3787 ) |
| 0.060 | 0.1590 | ( 0.0366 , | 0.4182 ) |
| 0.070 | 0.1730 | ( 0.0378 , | 0.4570 ) |
| 0.080 | 0.1862 | ( 0.0384 , | 0.4942 ) |
| 0.090 | 0.1987 | ( 0.0386 , | 0.5298 ) |
| 0.100 | 0.2107 | ( 0.0386 , | 0.5634 ) |
| 0.110 | 0.2222 | ( 0.0384 , | 0.5951 ) |
| 0.120 | 0.2333 | ( 0.0380 , | 0.6249 ) |
| 0.130 | 0.2441 | ( 0.0376 , | 0.6528 ) |
| 0.140 | 0.2545 | ( 0.0371 , | 0.6789 ) |
| 0.150 | 0.2646 | ( 0.0366 , | 0.7033 ) |
| 0.200 | 0.3120 | ( 0.0337 , | 0.8021 ) |
| 0.250 | 0.3553 | ( 0.0308 , | 0.8703 ) |
| 0.300 | 0.3959 | ( 0.0281 , | 0.9165 ) |
| 0.400 | 0.4718 | ( 0.0233 , | 0.9678 ) |
| 0.500 | 0.5436 | ( 0.0192 , | 0.9890 ) |
| 0.600 | 0.6140 | ( 0.0155 , | 0.9969 ) |
| 0.700 | 0.6854 | ( 0.0122 , | 0.9993 ) |
| 0.800 | 0.7609 | ( 0.0091 , | 0.9999 ) |
| 0.900 | 0.8468 | ( 0.0058 , | 1.0000 ) |
| 0.950 | 0.9001 | ( 0.0040 , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0030, 0.0321) | (0.0001, 0.0043) | (0.0487, 0.1420) |
| (0.0086, 0.0562) | (0.0009, 0.0173) | (0.0500, 0.1440) |
| (0.0143, 0.0735) | (0.0026, 0.0297) | (0.0571, 0.1548) |
| (0.0404, 0.1282) | (0.0142, 0.0733) | (0.0965, 0.2066) |

1

R O C F I T (JUNE 1993 VERSION) :

M A X I M U M  L I K E L I H O O D  E S T I M A T I O N
O F  A  B I N O R M A L  R O C  C U R V E
F R O M  R A T I N G  D A T A

DATA DESCRIPTION: Reader 10, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100. NO. OF ACTUALLY POSITIVE CASES = 100.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 91. | 6. | 2. | 1. | 0. |
| ACTUALLY POSITIVE CASES | 37. | 22. | 20. | 6. | 15. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0000 0.0100 0.0300 0.0900 1.0000
TPF: 0.0000 0.1500 0.2100 0.4100 0.6300 1.0000

INITIAL VALUES OF PARAMETERS:
A= 1.8597 B= 1.1295
Z(K)= 1.3410 1.8812 2.3268 2.5762
LOGL= -186.6256
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 5 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 1.6595 B= 0.9936
Z(K)= 1.3387 1.8972 2.4656 2.7230
LOGL= -186.2753
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.3016 | 0.1713 | 0.0444 | -0.0289 | -0.1175 | -0.1599 |
| B | 0.1713 | 0.1138 | 0.0102 | -0.0408 | -0.1014 | -0.1302 |
| Z( 1) | 0.0444 | 0.0102 | 0.0310 | 0.0251 | 0.0193 | 0.0167 |
| Z( 2) | -0.0289 | -0.0408 | 0.0251 | 0.0514 | 0.0715 | 0.0813 |
| Z( 3) | -0.1175 | -0.1014 | 0.0193 | 0.0715 | 0.1364 | 0.1605 |
| Z( 4) | -0.1599 | -0.1302 | 0.0167 | 0.0813 | 0.1605 | 0.2006 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.9249 | 0.4596 | -0.2320 | -0.5793 | -0.6499 |
| B | 0.9249 | 1.0000 | 0.1723 | -0.5331 | -0.8142 | -0.8616 |
| Z( 1) | 0.4596 | 0.1723 | 1.0000 | 0.6282 | 0.2976 | 0.2124 |
| Z( 2) | -0.2320 | -0.5331 | 0.6282 | 1.0000 | 0.8537 | 0.8011 |
| Z( 3) | -0.5793 | -0.8142 | 0.2976 | 0.8537 | 1.0000 | 0.9706 |
| Z( 4) | -0.6499 | -0.8616 | 0.2124 | 0.8011 | 0.9706 | 1.0000 |

AREA = 0.8804 STD. DEV.(AREA) = 0.0438

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1840 | ( 0.0429 , | 0.4670 ) |
| 0.010 | 0.2571 | ( 0.0914 , | 0.5109 ) |
| 0.020 | 0.3514 | ( 0.1766 , | 0.5656 ) |
| 0.030 | 0.4169 | ( 0.2456 , | 0.6060 ) |
| 0.040 | 0.4680 | ( 0.3013 , | 0.6405 ) |
| 0.050 | 0.5099 | ( 0.3465 , | 0.6716 ) |
| 0.060 | 0.5455 | ( 0.3835 , | 0.7002 ) |
| 0.070 | 0.5765 | ( 0.4141 , | 0.7266 ) |
| 0.080 | 0.6038 | ( 0.4398 , | 0.7511 ) |
| 0.090 | 0.6282 | ( 0.4616 , | 0.7736 ) |
| 0.100 | 0.6502 | ( 0.4803 , | 0.7943 ) |
| 0.110 | 0.6703 | ( 0.4967 , | 0.8132 ) |
| 0.120 | 0.6886 | ( 0.5111 , | 0.8305 ) |
| 0.130 | 0.7055 | ( 0.5240 , | 0.8462 ) |
| 0.140 | 0.7211 | ( 0.5356 , | 0.8605 ) |
| 0.150 | 0.7356 | ( 0.5462 , | 0.8736 ) |
| 0.200 | 0.7949 | ( 0.5882 , | 0.9228 ) |
| 0.250 | 0.8388 | ( 0.6195 , | 0.9530 ) |
| 0.300 | 0.8726 | ( 0.6448 , | 0.9717 ) |
| 0.400 | 0.9205 | ( 0.6859 , | 0.9902 ) |
| 0.500 | 0.9515 | ( 0.7201 , | 0.9969 ) |
| 0.600 | 0.9720 | ( 0.7511 , | 0.9992 ) |
| 0.700 | 0.9854 | ( 0.7815 , | 0.9998 ) |
| 0.800 | 0.9937 | ( 0.8134 , | 1.0000 ) |
| 0.900 | 0.9983 | ( 0.8520 , | 1.0000 ) |
| 0.950 | 0.9995 | ( 0.8792 , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0032, 0.1477) | (0.0002, 0.0275) | (0.0325, 0.4310) |
| (0.0068, 0.2146) | (0.0007, 0.0656) | (0.0408, 0.4716) |
| (0.0289, 0.4108) | (0.0096, 0.2524) | (0.0731, 0.5855) |
| (0.0903, 0.6291) | (0.0461, 0.4947) | (0.1602, 0.7492) |

# APPENDIX IV

# B IX

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 11, Mass Question

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100. NO. OF ACTUALLY POSITIVE CASES = 42.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 76. | 17. | 0. | 1. | 6. |
| ACTUALLY POSITIVE CASES | 13. | 1. | 0. | 2. | 26. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0600 0.0700 0.2400 1.0000
TPF: 0.0000 0.6190 0.6667 0.6905 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.6234 B= 0.1714
Z(K)= 0.7060 1.4761 1.5551
LOGL= -113.0300
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

PROCEDURE CONVERGES AFTER 4 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.6617 B= 0.2222
Z(K)= 0.7099 1.4142 1.5978
LOGL= -111.9829
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :

VARIANCE-COVARIANCE MATRIX:

| | | | | | |
|---|---|---|---|---|---|
| A | 0.0626 | 0.0207 | 0.0054 | -0.0002 | -0.0026 |
| B | 0.0207 | 0.0174 | 0.0017 | -0.0046 | -0.0074 |
| Z( 1) | 0.0054 | 0.0017 | 0.0189 | 0.0132 | 0.0121 |
| Z( 2) | -0.0002 | -0.0046 | 0.0132 | 0.0329 | 0.0316 |
| Z( 3) | -0.0026 | -0.0074 | 0.0121 | 0.0316 | 0.0415 |

CORRELATION MATRIX:

| | | | | | |
|---|---|---|---|---|---|
| A | 1.0000 | 0.6284 | 0.1570 | -0.0048 | -0.0516 |
| B | 0.6284 | 1.0000 | 0.0938 | -0.1911 | -0.2756 |
| Z( 1) | 0.1570 | 0.0938 | 1.0000 | 0.5295 | 0.4318 |
| Z( 2) | -0.0048 | -0.1911 | 0.5295 | 1.0000 | 0.8557 |
| Z( 3) | -0.0516 | -0.2756 | 0.4318 | 0.8557 | 1.0000 |

AREA = 0.7408 STD. DEV.(AREA) = 0.0756

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, UPPER BOUND) |
|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| 0.005 | 0.5356 | ( | 0.3324 | , 0.7297 | ) |
| 0.010 | 0.5575 | ( | 0.3684 | , 0.7342 | ) |
| 0.020 | 0.5813 | ( | 0.4066 | , 0.7411 | ) |
| 0.030 | 0.5963 | ( | 0.4297 | , 0.7468 | ) |
| 0.040 | 0.6074 | ( | 0.4462 | , 0.7519 | ) |
| 0.050 | 0.6164 | ( | 0.4590 | , 0.7565 | ) |
| 0.060 | 0.6240 | ( | 0.4694 | , 0.7608 | ) |
| 0.070 | 0.6307 | ( | 0.4782 | , 0.7649 | ) |
| 0.080 | 0.6366 | ( | 0.4856 | , 0.7688 | ) |
| 0.090 | 0.6420 | ( | 0.4921 | , 0.7725 | ) |
| 0.100 | 0.6469 | ( | 0.4979 | , 0.7761 | ) |
| 0.110 | 0.6514 | ( | 0.5030 | , 0.7796 | ) |
| 0.120 | 0.6556 | ( | 0.5076 | , 0.7829 | ) |
| 0.130 | 0.6596 | ( | 0.5117 | , 0.7862 | ) |
| 0.140 | 0.6633 | ( | 0.5155 | , 0.7894 | ) |
| 0.150 | 0.6669 | ( | 0.5190 | , 0.7925 | ) |
| 0.200 | 0.6825 | ( | 0.5329 | , 0.8070 | ) |
| 0.250 | 0.6956 | ( | 0.5428 | , 0.8203 | ) |
| 0.300 | 0.7072 | ( | 0.5503 | , 0.8325 | ) |
| 0.400 | 0.7276 | ( | 0.5609 | , 0.8549 | ) |
| 0.500 | 0.7459 | ( | 0.5679 | , 0.8754 | ) |
| 0.600 | 0.7636 | ( | 0.5729 | , 0.8947 | ) |
| 0.700 | 0.7817 | ( | 0.5765 | , 0.9136 | ) |
| 0.800 | 0.8020 | ( | 0.5789 | , 0.9329 | ) |
| 0.900 | 0.8280 | ( | 0.5800 | , 0.9546 | ) |
| 0.950 | 0.8478 | ( | 0.5795 | , 0.9681 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0550, 0.6204) | (0.0229, 0.5862) | (0.1154, 0.6537) |
| (0.0786, 0.6359) | (0.0384, 0.6058) | (0.1448, 0.6651) |
| (0.2389, 0.6928) | (0.1637, 0.6715) | (0.3298, 0.7136) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 11, MicroCalcifications

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100. NO. OF ACTUALLY POSITIVE CASES = 51.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 95. | 0. | 0. | 1. | 4. |
| ACTUALLY POSITIVE CASES | 26. | 2. | 0. | 0. | 23. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0400 0.0500 0.0500 1.0000
TPF: 0.0000 0.4510 0.4510 0.4902 1.0000

INITIAL VALUES OF PARAMETERS:

```
A=  1.5769    B=  0.9713
Z(K)=  1.5452    1.6452    1.7511
LOGL=   -67.9594
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


PROCEDURE CONVERGES AFTER   5 ITERATIONS.


       FINAL VALUES OF PARAMETERS:
A=  1.6025    B=  0.9900
Z(K)=  1.6444    1.7102    1.7441
LOGL=   -66.6294
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


       VARIANCE-COVARIANCE MATRIX:
A       4.1910  2.4630  0.0735 -0.0363 -0.0944
B       2.4630  1.4733  0.0178 -0.0482 -0.0832
Z( 1)   0.0735  0.0178  0.0446  0.0434  0.0428
Z( 2) -0.0363 -0.0482  0.0434  0.0474  0.0483
Z( 3) -0.0944 -0.0832  0.0428  0.0483  0.0512


       CORRELATION MATRIX:
A       1.0000  0.9912  0.1699 -0.0814 -0.2037
B       0.9912  1.0000  0.0695 -0.1825 -0.3028
Z( 1)   0.1699  0.0695  1.0000  0.9449  0.8960
Z( 2) -0.0814 -0.1825  0.9449  1.0000  0.9806
Z( 3) -0.2037 -0.3028  0.8960  0.9806  1.0000


      AREA =  0.8726       STD. DEV.(AREA) =  0.1617
1
ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:


   FPF       TPF        (LOWER BOUND, UPPER BOUND)

  0.005     0.1716      (   0.0008  ,   0.8977   )
  0.010     0.2416      (   0.0095  ,   0.8277   )
  0.020     0.3332      (   0.0688  ,   0.7331   )
  0.030     0.3975      (   0.1615  ,   0.6802   )
  0.040     0.4478      (   0.2436  ,   0.6673   )
  0.050     0.4895      (   0.2873  ,   0.6945   )
  0.060     0.5251      (   0.2958  ,   0.7461   )
  0.070     0.5561      (   0.2860  ,   0.8016   )
  0.080     0.5836      (   0.2690  ,   0.8504   )
  0.090     0.6083      (   0.2500  ,   0.8896   )
  0.100     0.6306      (   0.2310  ,   0.9197   )
  0.110     0.6510      (   0.2128  ,   0.9421   )
  0.120     0.6697      (   0.1959  ,   0.9586   )
  0.130     0.6870      (   0.1802  ,   0.9706   )
  0.140     0.7030      (   0.1658  ,   0.9792   )
  0.150     0.7178      (   0.1525  ,   0.9853   )
  0.200     0.7792      (   0.1010  ,   0.9976   )
  0.250     0.8251      (   0.0672  ,   0.9996   )
  0.300     0.8608      (   0.0448  ,   0.9999   )
  0.400     0.9118      (   0.0195  ,   1.0000   )
  0.500     0.9455      (   0.0080  ,   1.0000   )
  0.600     0.9681      (   0.0029  ,   1.0000   )
  0.700     0.9831      (   0.0009  ,   1.0000   )
  0.800     0.9926      (   0.0002  ,   1.0000   )
```

```
          0.900     0.9980       (   0.0000  ,    1.0000   )
          0.950     0.9994       (   0.0000  ,    1.0000   )



        ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC
        CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95%
        CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:


 EXPECTED OPERATING POINT          LOWER BOUND          UPPER BOUND
     ( FPF ,   TPF )            ( FPF ,   TPF )      ( FPF ,   TPF )

     (0.0406, 0.4506)           (0.0143, 0.2866)     (0.0967, 0.6236)
     (0.0436, 0.4639)           (0.0163, 0.3040)     (0.0996, 0.6299)
     (0.0500, 0.4898)           (0.0198, 0.3316)     (0.1093, 0.6497)
1                            R O C F I T (JUNE 1993 VERSION) :

      M A X I M U M   L I K E L I H O O D   E S T I M A T I O N
           O F   A   B I N O R M A L   R O C   C U R V E
                F R O M   R A T I N G   D A T A


        DATA DESCRIPTION: Reader 11, FAS/AD

        DATA COLLECTED IN  5 CATEGORIES
        WITH CATEGORY  5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

        NO. OF ACTUALLY NEGATIVE CASES =  100.     NO. OF ACTUALLY POSITIVE CASES =   23.

        RESPONSE DATA:
         CATEGORY                    1      2      3      4      5
         ACTUALLY NEGATIVE CASES    73.     1.     0.    14.    12.
         ACTUALLY POSITIVE CASES    13.     1.     0.     5.     4.

        OBSERVED OPERATING POINTS:
         FPF: 0.0000 0.1200 0.2600 0.2700 1.0000
         TPF: 0.0000 0.1739 0.3913 0.4348 1.0000

              INITIAL VALUES OF PARAMETERS:
        A=  0.6094    B=  1.3192
        Z(K)=  0.6125    0.6430    1.1751
        LOGL=  -106.1220
        CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


        PROCEDURE CONVERGES AFTER   3 ITERATIONS.


              FINAL VALUES OF PARAMETERS:
        A=  0.6843    B=  1.3990
        Z(K)=  0.6117    0.6559    1.1707
        LOGL=  -105.9773
        CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE :


              VARIANCE-COVARIANCE MATRIX:
        A       0.3212  0.2899  0.0325  0.0300 -0.0014
        B       0.2899  0.3677  0.0120  0.0086 -0.0324
        Z( 1)   0.0325  0.0120  0.0180  0.0176  0.0132
        Z( 2)   0.0300  0.0086  0.0176  0.0181  0.0140
        Z( 3)  -0.0014 -0.0324  0.0132  0.0140  0.0263
```

CORRELATION MATRIX:

| | | | | | |
|---|---|---|---|---|---|
| A | 1.0000 | 0.8435 | 0.4273 | 0.3936 | -0.0149 |
| B | 0.8435 | 1.0000 | 0.1470 | 0.1056 | -0.3302 |
| Z( 1) | 0.4273 | 0.1470 | 1.0000 | 0.9726 | 0.6091 |
| Z( 2) | 0.3936 | 0.1056 | 0.9726 | 1.0000 | 0.6421 |
| Z( 3) | -0.0149 | -0.3302 | 0.6091 | 0.6421 | 1.0000 |

AREA = 0.6547 STD. DEV.(AREA) = 0.0889

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR TRUE-POSITIVE FRACTION AT EACH SPECIFIED FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.0018 | ( 0.0000 , | 0.2380 ) |
| 0.010 | 0.0051 | ( 0.0000 , | 0.2586 ) |
| 0.020 | 0.0143 | ( 0.0001 , | 0.2840 ) |
| 0.030 | 0.0257 | ( 0.0004 , | 0.3022 ) |
| 0.040 | 0.0387 | ( 0.0011 , | 0.3174 ) |
| 0.050 | 0.0529 | ( 0.0026 , | 0.3310 ) |
| 0.060 | 0.0679 | ( 0.0049 , | 0.3438 ) |
| 0.070 | 0.0837 | ( 0.0084 , | 0.3561 ) |
| 0.080 | 0.1000 | ( 0.0130 , | 0.3683 ) |
| 0.090 | 0.1167 | ( 0.0188 , | 0.3804 ) |
| 0.100 | 0.1337 | ( 0.0259 , | 0.3927 ) |
| 0.110 | 0.1511 | ( 0.0341 , | 0.4053 ) |
| 0.120 | 0.1686 | ( 0.0434 , | 0.4182 ) |
| 0.130 | 0.1863 | ( 0.0536 , | 0.4316 ) |
| 0.140 | 0.2041 | ( 0.0646 , | 0.4456 ) |
| 0.150 | 0.2219 | ( 0.0762 , | 0.4601 ) |
| 0.200 | 0.3110 | ( 0.1372 , | 0.5426 ) |
| 0.250 | 0.3979 | ( 0.1919 , | 0.6380 ) |
| 0.300 | 0.4805 | ( 0.2348 , | 0.7342 ) |
| 0.400 | 0.6295 | ( 0.2939 , | 0.8855 ) |
| 0.500 | 0.7531 | ( 0.3348 , | 0.9637 ) |
| 0.600 | 0.8504 | ( 0.3685 , | 0.9921 ) |
| 0.700 | 0.9218 | ( 0.4003 , | 0.9990 ) |
| 0.800 | 0.9687 | ( 0.4343 , | 0.9999 ) |
| 0.900 | 0.9934 | ( 0.4784 , | 1.0000 ) |
| 0.950 | 0.9986 | ( 0.5130 , | 1.0000 ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.1209, 0.1702) | (0.0683, 0.0811) | (0.1968, 0.3053) |
| (0.2559, 0.4078) | (0.1789, 0.2735) | (0.3475, 0.5540) |
| (0.2704, 0.4319) | (0.1908, 0.2948) | (0.3637, 0.5779) |

1 R O C F I T (JUNE 1993 VERSION) :

M A X I M U M L I K E L I H O O D E S T I M A T I O N
O F A B I N O R M A L R O C C U R V E
F R O M R A T I N G D A T A

DATA DESCRIPTION: Reader 11, Benign or Malignant

DATA COLLECTED IN 5 CATEGORIES
WITH CATEGORY 5 REPRESENTING STRONGEST EVIDENCE OF POSITIVITY (E.G., THAT ABNORMALIT

NO. OF ACTUALLY NEGATIVE CASES = 100. NO. OF ACTUALLY POSITIVE CASES = 100.

RESPONSE DATA:

| CATEGORY | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| ACTUALLY NEGATIVE CASES | 56. | 31. | 13. | 0. | 0. |
| ACTUALLY POSITIVE CASES | 21. | 38. | 18. | 14. | 9. |

OBSERVED OPERATING POINTS:
FPF: 0.0000 0.0000 0.0000 0.1300 0.4400 1.0000
TPF: 0.0000 0.0900 0.2300 0.4100 0.7900 1.0000

INITIAL VALUES OF PARAMETERS:
A= 0.8157 B= 0.7526
Z(K)= 0.1507 1.1265 2.4762 2.5762
LOGL= -270.4485
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

PROCEDURE CONVERGES AFTER 7 ITERATIONS.

FINAL VALUES OF PARAMETERS:
A= 0.8626 B= 0.7836
Z(K)= 0.1283 1.2717 2.1074 2.8588
LOGL= -249.0090
CHI-SQUARE GOODNESS OF FIT NOT CALCULATED BECAUSE SOME EXPECTED CELL FREQUENCIES ARE

VARIANCE-COVARIANCE MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 0.0316 | 0.0134 | 0.0127 | 0.0070 | -0.0015 | -0.0119 |
| B | 0.0134 | 0.0174 | 0.0044 | -0.0078 | -0.0229 | -0.0396 |
| Z( 1) | 0.0127 | 0.0044 | 0.0157 | 0.0086 | 0.0045 | 0.0006 |
| Z( 2) | 0.0070 | -0.0078 | 0.0086 | 0.0247 | 0.0289 | 0.0356 |
| Z( 3) | -0.0015 | -0.0229 | 0.0045 | 0.0289 | 0.0647 | 0.0826 |
| Z( 4) | -0.0119 | -0.0396 | 0.0006 | 0.0356 | 0.0826 | 0.1506 |

CORRELATION MATRIX:

| | | | | | | |
|---|---|---|---|---|---|---|
| A | 1.0000 | 0.5699 | 0.5690 | 0.2500 | -0.0329 | -0.1725 |
| B | 0.5699 | 1.0000 | 0.2638 | -0.3768 | -0.6815 | -0.7725 |
| Z( 1) | 0.5690 | 0.2638 | 1.0000 | 0.4374 | 0.1427 | 0.0120 |
| Z( 2) | 0.2500 | -0.3768 | 0.4374 | 1.0000 | 0.7221 | 0.5829 |
| Z( 3) | -0.0329 | -0.6815 | 0.1427 | 0.7221 | 1.0000 | 0.8373 |
| Z( 4) | -0.1725 | -0.7725 | 0.0120 | 0.5829 | 0.8373 | 1.0000 |

AREA = 0.7514 STD. DEV.(AREA) = 0.0382

1

ESTIMATED BINORMAL ROC CURVE, WITH LOWER AND UPPER
BOUNDS ON ASYMMETRIC 95% CONFIDENCE INTERVAL FOR
TRUE-POSITIVE FRACTION AT EACH SPECIFIED
FALSE-POSITIVE FRACTION:

| FPF | TPF | (LOWER BOUND, | UPPER BOUND) |
|---|---|---|---|
| 0.005 | 0.1238 | ( 0.0441 , | 0.2718 ) |
| 0.010 | 0.1684 | ( 0.0728 , | 0.3207 ) |
| 0.020 | 0.2275 | ( 0.1178 , | 0.3791 ) |
| 0.030 | 0.2704 | ( 0.1544 , | 0.4187 ) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.040 | 0.3052 | ( | 0.1860 | , | 0.4497 | ) |
| 0.050 | 0.3349 | ( | 0.2142 | , | 0.4756 | ) |
| 0.060 | 0.3609 | ( | 0.2397 | , | 0.4982 | ) |
| 0.070 | 0.3844 | ( | 0.2631 | , | 0.5183 | ) |
| 0.080 | 0.4057 | ( | 0.2847 | , | 0.5366 | ) |
| 0.090 | 0.4254 | ( | 0.3048 | , | 0.5534 | ) |
| 0.100 | 0.4436 | ( | 0.3237 | , | 0.5690 | ) |
| 0.110 | 0.4607 | ( | 0.3415 | , | 0.5837 | ) |
| 0.120 | 0.4768 | ( | 0.3582 | , | 0.5975 | ) |
| 0.130 | 0.4920 | ( | 0.3741 | , | 0.6106 | ) |
| 0.140 | 0.5064 | ( | 0.3892 | , | 0.6230 | ) |
| 0.150 | 0.5201 | ( | 0.4036 | , | 0.6350 | ) |
| 0.200 | 0.5805 | ( | 0.4667 | , | 0.6880 | ) |
| 0.250 | 0.6309 | ( | 0.5188 | , | 0.7329 | ) |
| 0.300 | 0.6744 | ( | 0.5632 | , | 0.7719 | ) |
| 0.400 | 0.7468 | ( | 0.6364 | , | 0.8364 | ) |
| 0.500 | 0.8058 | ( | 0.6965 | , | 0.8870 | ) |
| 0.600 | 0.8556 | ( | 0.7491 | , | 0.9265 | ) |
| 0.700 | 0.8985 | ( | 0.7977 | , | 0.9566 | ) |
| 0.800 | 0.9360 | ( | 0.8454 | , | 0.9787 | ) |
| 0.900 | 0.9690 | ( | 0.8970 | , | 0.9932 | ) |
| 0.950 | 0.9843 | ( | 0.9286 | , | 0.9977 | ) |

ESTIMATES OF EXPECTED OPERATING POINTS ON FITTED ROC CURVE, WITH LOWER AND UPPER BOUNDS OF ASYMMETRIC 95% CONFIDENCE INTERVALS ALONG THE CURVE FOR THOSE POINTS:

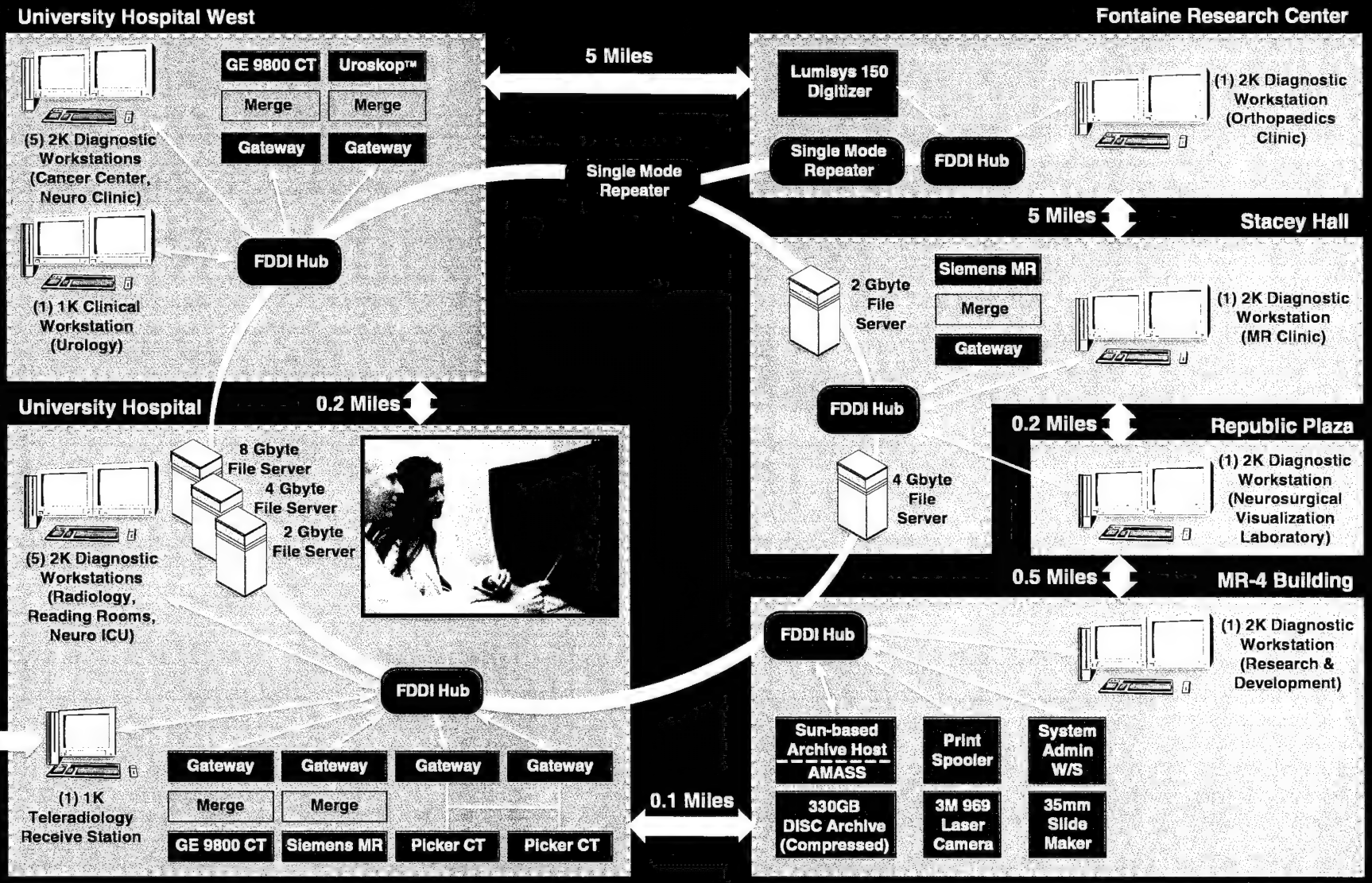
| EXPECTED OPERATING POINT ( FPF , TPF ) | LOWER BOUND ( FPF , TPF ) | UPPER BOUND ( FPF , TPF ) |
|---|---|---|
| (0.0021, 0.0842) | (0.0001, 0.0242) | (0.0179, 0.2172) |
| (0.0175, 0.2151) | (0.0046, 0.1191) | (0.0538, 0.3453) |
| (0.1017, 0.4468) | (0.0571, 0.3537) | (0.1676, 0.5428) |
| (0.4490, 0.7770) | (0.3543, 0.7155) | (0.5467, 0.8301) |

# APPENDIX

## 5 A

# The University of Virginia PACS

EMED




AS9504-78

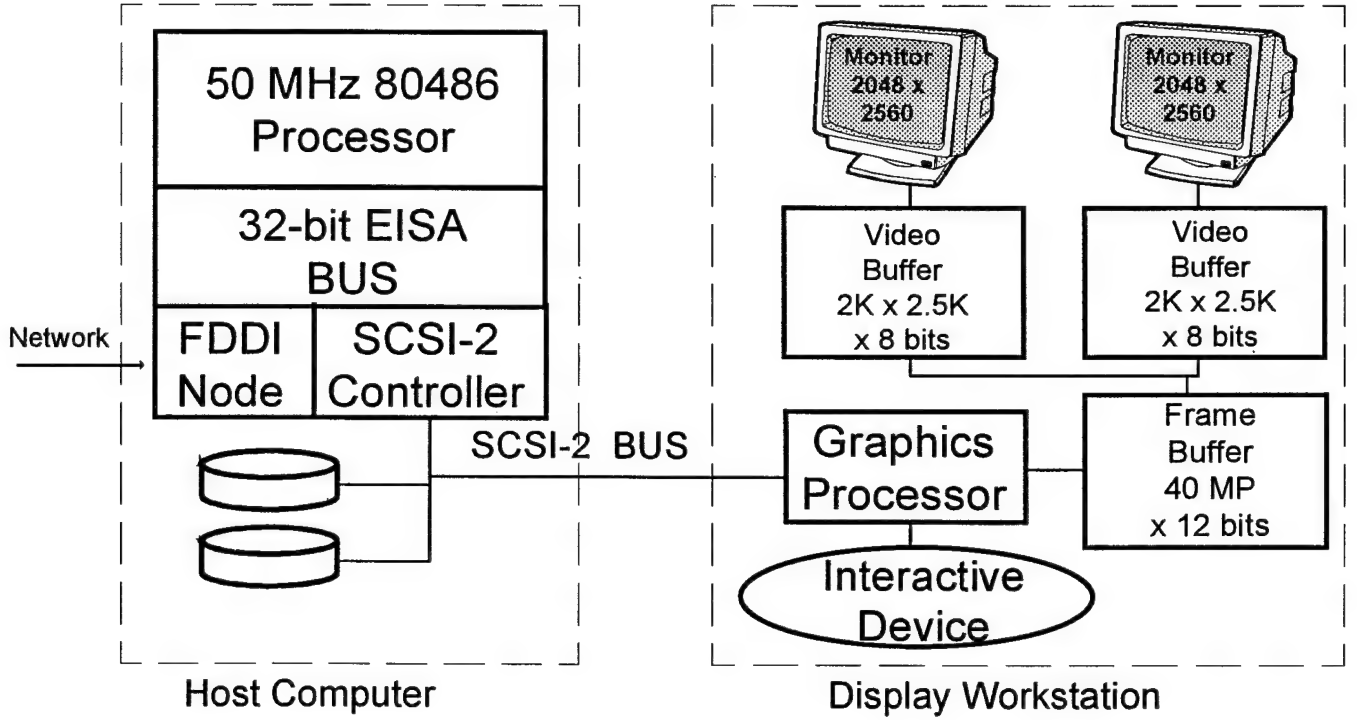
Third Party Interfaces [illegible] University of Virginia Legacy Systems

An E-Systems Company

# APPENDIX

## 5 B

# DISPLAY SYSTEM



# APPENDIX

5 C

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

*Brent K. Stewart, Ph.D.*
*Associate Professor and Director*
*Diagnostic Physics Laboratory*
*Department of Radiology, RC-05*

*NW040J Health Sciences Bldg.*
*206.548.6252 (office)*
*206.543.3495 (fax)*
*bstewart@u.washington.edu*

19 March 1995

Samuel J. Dwyer III, Ph.D.
Professor
Department of Radiology
University of Virginia
MR-4 Room 1190
Charlottesville, VA 22908

Dear Sam:

Please find enclosed the findings of my visit to the Medical College of Virginia on 1/27/95 and the University of Virginia on 1/28/95 as consultant on the US Army Medical Research and Development Command grant entitled: "Evaluation of a Digital Telemammography System: a Model for a Regional System."

Visit to the Medical College of Virginia

On 1/27/95, I met with Ellen Shaw de Parades, M.D., Chief of Mammography at the Medical College of Virginia's Department of Radiology and Principal Investigator of the telemammography grant. The purpose of the consulting at the Medical College of Virginia was to analyze the design of the Receiver Operator Characteristics (ROC) studies, comment on the method of selecting images for the study, examine the images already collected for the study, and discuss strategies for analysis of the ROC after the testing has concluded. I prepared a list of questions (given below). I also sat through a few of the tests to give advice on reading room environment, e.g., view box luminance and glare.

I submitted a list of questions to Dr. de Parades regarding the analog film and digital softcopy ROC testing:
1. Has the ROC testing commenced and if so, how far along is it?
2. Has the ROC study design changed significantly from that stated in the initial proposal?
3. How are the mammograms for the ROC study selected?
4. You are selecting age-matched normal controls. Are you matching these normal mammograms for overall parenchymal density as well? If so, how are you accomplishing this?
5. Are the initial 200 mammograms cited in the grant application digitized yet? If so, what is keeping you from initiating the digital softcopy ROC portion of the study?

6. For mammogram digitization, what quality control/assurance program have you instituted?
7. In the original grant application, it was stated that the digital softcopy review might occur on any of ten different 2K resolution workstations throughout the UVA Department of Radiology. Unless these workstation's monitors are periodically and effectively calibrated, this might confound the ROC results.
8. In the original grant application, the images read at the remote Northridge outpatient clinic were to be subjected to a preference test (scale: 1-5). Would it be better to have these cases overread by mammographers at UVA and statistically calculate the analysis of variance?
9. Reading all of the analog images first produces a bias in the ROC test. It would be better to have one-half of the radiologists read the digital softcopy images first and the other radiologists read the analog images first. Of course, as there will be multiple reading sessions for each modality, each session could be randomly picked from analog or digital. This bias may, of course, be confounded as the radiologists will know which images are analog and which are digital.
10. Is ground truth available for all of the films to be used in the study? What aside information are you using to establish ground truth? Is there a truth committee? If so, who is on it and how do they arrive a conclusion regarding a case without unanimity?
11. A random number generator should also be used for ordering the analog and digital normals and abnormals in each of the ROC study sessions. Is this the case and if not, why not?
12. Who will be collecting, collating and performing the analysis of the ROC test result data? Will you be using one of the standard software packages like ROCFIT or CORROC from the University of Chicago?
13. In the grant, it is stated that in addition to the 50μm digitized radiographs, that some would be digitized at 23μm. If so, how many and are you adding this as another section of the original ROC study?
14. It appears from the grant application that the ROC results will be pooled for the four different pathology types. Is this still the case? Will you achieve sufficient statistical power in the non-pooled case?
15. How has splitting the grant across institutions (UVA and MCV) affected the design and execution of the proposed work?
16. Will you be using the BIRADS system information for patient selection? It doesn't appear that the RadCare radiology information system in place at the MCV will facilitate on-line image selection for the ROC. What system will you have to help automate patient selection?
17. Are there any problems in selecting cases from both MCV and UVA in terms of image quality differences? There should be differences in film type, screen type, mammography machine output, film processing, etc.
18. It will be possible to time the readers using the computer in the softcopy display workstation. Are you planning on doing this? If so, could the radiologist write-down the start and end times on the scoring sheets?

Advice on ROC Reading Sessions:
I also sat through three sessions of analog ROC testing with one private practice mammographer and two MCV faculty radiologists. A specific mammography view panel was used, This viewing panel had the capability of shuttering out extraneous light around the edges of the films, however, this was not done in all cases by all radiologists. Both 8"x10" and 10"x12" films were used. One row was used at a time. The medio-lateral views paired on the left, the cranial-caudal radiographs were paired on the right. The room, the mammography reading room, was fairly quiet, but was simultaneously used by another radiologist and a resident, as well as Dr. de Parades during the ROC sessions. The readers did interrupt their reading sessions to speak with colleagues or answer the phone/pager. There were no overhead lights to contend with and there was no light reflections on the ROC viewbox.

A magnifying lens was provided (will an analogous "zooming" capability be added to the softcopy display workstation as well?). A hot lamp was available (will an analogous grayscale look-up table facility be added to the softcopy display workstation as well?).

The reading sessions consist of 50 patient studies, each consisting of four radiographs (2 CC/2MLO). There is one three ring binder notebook for each reader. All of the instructions for each reader are in the notebooks, as well as all of the reader responses for each patient case read.

On the average, the magnifying glass was used in 96% of the cases read, whereas, the hot lamp was used only sparingly, about 10% of the time. The radiologists always started with the MLO views and then the CC views. Any zooming and panning would need to happen quickly to be effective (not slowing down the reading process significantly. There were several instances of the radiologists being interrupted for pages and consultations. If a timer were to be integrated into the softcopy reading workstation, a pause button would be useful.

There were several instances where films were displaced vertically to come into registration (vertical shift). This capability may need to be added to the digital review workstation. It would be very hard to be the video monitors close enough for bi-lateral comparison. Digital panning may be necessary. On the average it took two minutes and 18 seconds to read one of the 50 studies in the ROC study list.

Visit to the University of Virginia

On 1/28/95, I met with Samuel J. Dwyer, Ph.D., Director of PACS and Co-Prinicpal Investigator of the telemammography grant at the Medical College of Virginia's Department of Radiology. I also met with Beth Elias, B.S., the systems analyst for the telemammography grant. The purpose of the consulting at the University of Virginia was to examine and provide recommendations for mammogram digitization, image presentation on the viewing monitors, and image processing functionality.

I made several recommendations regarding image digitization quality control, specifically daily digitization of a standard test pattern and periodic cleaning and calibration of the digitizer. I also suggested several means of displaying the image digitally to the radiologists for that portion of the ROC testing. There were also questions regarding where an additional image reading station for the MCV portion of the digital ROC testing were coming from. It might be the case the E-systems will loan as system to the MCV for the duration of the ROC testing. Due to construction and a snow storm, it was not convenient to visit the Northridge site.

Image Digitization:
The images are being digitized at the UVA under the direction of Ms. Elias. A Lumisys digitizer, model 150, is being used for the digitization. A SMPTE (Society of Motion Picture Test Engineers) is being used for daily grayscale and resolution quality control. The mirrors of the system are cleaned bi-monthly. Every four months, a field engineer from E-systems recalibrated the digitizer densitometry.

It was suggested that the name of the patient, the patient identification number, the date of the examination and the name of the institution be masked off with electrical tape prior to digitization. It was also suggested that a single normal mammogram be used for daily grayscale quality control. This mammogram could be digitized every day, prior to digitization of mammograms for the digital part of the study. Once registered spatially, the daily mammogram could be digitally subtracted from the baseline one and the difference image studied. If it appeared that there is more than simple noise differences in the difference image, e.g., structure evident, then the densitometry might need to be adjusted more often than every four months.

Image Presentation on the Viewing Monitors:
How many monitors are going to be used for the workstations in the study? Only two. It was observed above that the radiologists reviewing the analog cases switched back and forth between the CC and MLO pairs quite often. If only two video monitors were used, this would severely hamper both the comparison necessary for diagnosis, but significantly increase the interpretation time as well. Methods were discussed with Ms. Elias for quickly context switching between the two sets (MLO and CC) of mammograms for each patient. The limiting factor here is that it is only possible to load two mammograms into the E-systems MegaScan 2K monitor digital frame buffer (32 Mbyte limit). Having to re-paint the frame buffers from magnetic disk for each MLO <-> CC context switch will most likely be interminably slow.

It was also suggested that a sequential worklist of patients for the softcopy review workstation portion of the ROC study be instituted. Currently, the radiologist has to select images from a pull-down menu list with small font. The easiest thing for the radiologists to have to do would be to push a "hot key" to advance to the next patient in the ROC study list automatically. Otherwise, with the limitations of the MLO <-> CC context switching and having to search through a complicated list of code numbers, the radiologists will become frustrated, which might impact the results of that portion of the ROC test.

Image Processing:
In order to emulate the functionality of the hot lamp and the magnifying glass, image processing functions will be implemented on the digital viewing station. However, the zooming functionality included with the E-systems MegaScan monitors looks overly complicated for a function that the radiologists used about 96% of the time in the analog portions of the ROC tests.

With regards to grayscale modifications of the digital mammograms, the user can change both the brightness and the contrast. This is accomplished fairly easily using the mouse, moving it either up or down for contrast modification and left to right for brightness/darkness changes. However, as there are three buttons on the optical mouse, a specific series of button pushes are necessary to invoke and dismiss the grayscale look-up table modification software. The radiologists are going to have to have something simple to get through the set of 50 image cases in a reasonable amount of time. I can foresee a great amount of frustration with the current user interface for zooming and look-up table modification. All but one of the mouse buttons should be disabled for the ROC testing.

Please let me know if there is anything else that you may require in this matter. It has been a pleasure working with you and Dr. de Parades on the telemammography project.

Sincerely,

Brent K. Stewart

Brent K. Stewart, Ph.D.
Consultant to the US Army Medical Research and Development Command Grant
Evaluation of a Digital Telemammography System: a Model for a Regional System